EVALUATION OF LUMBOSACRAL ORTHOSIS IN FLEXION AND EXTENSION MOVEMENTS OF LUMBAR SPINE

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ABSTRACT

Lumbosacral orthosis (LSO) is a type of spinal orthosis that has been recommended for abdominal support, pain management, and motion or positional control. By implemented radiographic technique, objectives of this study was to evaluate the changes of lumbar lordosis in flexion and extension of trunk movements with and without wearing the LSO measured by Cobb, Centroid, and Posterior Tangent techniques and to correlate the value of lordotic angles in particular posture. Ten healthy male subjects without any history of low back pain participated and a semi-rigid LSO was utilized. Antero-posterior and lateral radiographs of spine images during neutral, flexion, and extension postures, with and without LSO, were captured. Lateral radiographic images were observed by five observers to determine the lumbar lordosis angles by implementation of Cobb, Centroid, and Posterior Tangent methods. Hand drawn line technique was applied on each image using a ruler while lordotic angles were measured using a protractor. Statistical analysis was completed using SPSS (Statistical Package for the Social Sciences). Lumbar lordoses ranged from 6.16° to 14.88° without orthosis and 15.24° to 17.92° with orthosis for trunk flexion and as for trunk extension with and without orthosis, lumbar lordoses ranged from 39.92° to 57.96° and 36.24° to 56.88°, respectively. Correlation between the methods was significant. In addition, there was a significant difference between lumbar lordosis of trunk flexion measured by Cobb and Centroid techniques. However, there were only small changes in trunk extension with and without orthosis measured by Cobb, Centroid, and Posterior Tangent methods. Reliability among observers was also high. Present results indicate that the lumbar lordosis increased when the lumbosacral orthosis was used in both flexion and extension postures.

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ORIGINAL LITERARY WORK DECLARATION

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LIST OF ARTICLES SUBMITTED FOR PUBLICATIONS

The research described in this dissertation has led to the publication of the following papers:

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CHAPTER 1: INTRODUCTION

The main biomechanical function of the spinal column is to support large compressive preloads during activities of daily living (ADL) while allowing physiologic mobility. Loads on the human spine are produced by gravitational forces that induced by the mass of body segments, external forces and moments due to physical activities, and muscle tension (Patwardhan *et al*, 2008). Etiology of spinal disorders is determined by the mechanical loads applied on the spine. Orthoses have been used as non-operative alternatives to correct spinal disorders and to enhance the spine stability. In post-operative treatments, orthoses are used to protect the surgical constructs. In addition, the post-operative orthosis should limit the gross motion of the trunk during activities of normal daily living (Krag *et al*, 2003). Three basic reasons for the recommendation of a spinal orthosis are as an abdominal support, as a tool for pain management, and for motion or positional control. Generally, spinal orthoses are categorized by the vertebral level such as sacral orthosis (SO), lumbosacral orthosis (LSO), and thoracolumbosacral orthosis (TLSO) (Romo *et al*, 2008).

1.1 Problem statement

Lumbosacral orthosis is a class I medical device that is used in conservative and post-operative management of low back pain. It is also used to decrease lumbar force or motion (Krag *et al*, 2003). This orthosis is referred to as abdominal support, lumbar support, and abdominal belt (Cholewicki *et al*, 2010). Low back pain has been related to anthropometric, postural, muscular, and mobility characteristics and the etiologic factors affected by obesity, increased lumbar lordosis, poor abdominal muscle strength, imbalance between flexor and extensor trunk strength, reduced spinal mobility, tight hamstrings, and leg-length inequality (Bayramoglu *et al*, 2001). Lumbosacral orthosis is commonly used in the relief of low back pain although there is little strong scientific evidence of its clinical effectiveness (Huynh *et al*, 1998). Mechanisms of action of lumbar support have been frequently investigated in particular concerning spinal behavior but unfortunately the results are remains controversial (Calmels *et al*, 2009; Fayolle-Minon & Calmels, 2008). However, the use of lumbosacral orthosis increases due to a high satisfaction rate among patients with low back pain (Cholewicki, 2004) who were convinced it would restricts the lumbar motion, decreases disc pressure, and changes in lumbar posture (Thoumie *et al*, 1998). Therefore, low back pain patient perceived added support from wearing a lumbosacral orthosis which increases their confidence in undertaking daily activities. As discussed by Huynh *et al* (1998), the above problems occurred because of different evaluation techniques that have been used and different lumbar support that have been investigated. Difficulties in making accurate comparison existed because biomechanical effects vary depending on the types of orthosis used and. Those scenarios have actually inspired the design of the present study.

1.2 Objectives of the study

The purpose of this study is to evaluate the changes of lumbar lordosis in flexion and extension of trunk movements, with and without wearing the lumbosacral orthosis. Lumbar lordosis is defined as the anterior convexity of the lumbar spine, in the sagittal plane (Whittle & Levine, 1997). The attempt is to obtain data concerning the efficiency of a semi rigid lumbosacral orthosis by implementation of radiographic technique onto the lumbar spine. In addition, this work also attempted to find the correlation between the value of lordotic angle (in trunk flexion and extension) and the measurement methods applied (Cobb method, Centroid method, and Posterior Tangent method). Effects of LSO on lumbar spine lordotic angles will be also investigated.

1.3 Hypothesis

The relief of low back pain while wearing lumbar orthoses could be related to the limitation of spinal movements or to the increase of intra-abdominal pressure allowing a proportion of the body load to be transmitted through the abdomen rather than the spine (Huynh *et al*, 1998). In addition, there is also a study which reported that a lumbar support caused changes in the average position of the lumbar spine (Thoumie *et al*, 1998). It is proven that the lumbosacral orthosis possess limited ability to reduce intervertebral motions (Cholewicki, 2004). Therefore, the hypotheses of the present study are; there will be significant differences between the lumbar lordosis of trunk flexion and extension, with and without orthosis, and there is no significant difference between the methods used in assessing lumbar lordosis for trunk flexion and extension, with and without wearing the LSO. Gross motion of the spine will reduced when the orthosis is attached onto the subjects. In other words, the movement of the spine is restricted when the trunk is supported compared to without applying the lumbosacral orthosis.

1.4 Scope of the study

The present study evaluated the effectiveness of a lumbosacral orthosis by measuring the lordotic angles of x-ray images in sagittal plane. Digital x-ray images of subjects performing trunk flexion and extension with and without LSO were obtained and those images were printed out. The lordotic angles of printed digital x-ray images were then measured by Cobb, Centroid, and Posterior Tangent methods. These techniques will be applied to the x-ray images of the subjects with and without wearing the orthosis, to facilitate the comparison purposes. The measurement data were analyzed and the assessment of the LSO is carried out. Further, the results will be compared to results of previous researches.

1.5 Significance of the study

Evaluations of lumbosacral orthoses or abdominal belts have been designed in many ways. This statement will be further elaborate in the next chapter. Current situations which have motivated this study are as follows: (i) there is no systematic reduction in the spinal movement when a task is carried out with and without the orthoses and, (ii) as to date, there is no study carried out to evaluate the effectiveness of the standard type lumbosacral orthosis used in local hospitals for low back pain. As far as the author is concerned, this is the first attempt to evaluate the effectiveness of common orthosis used in the local hospitals.

1.6 Outline of the report

Overview of the principles, components, uses, and studies on lumbosacral orthosis is presented in Chapter 2 of this dissertation. This chapter elaborated on the studies carried out by previous researchers in evaluations or investigations of the spinal orthoses and their effectiveness in medical and engineering perspectives. Chapter 3 shows the method implemented in this study and the materials utilized in the investigation. Reasons for each technique and material used are stated. Relevant theoretical analysis regarding the biomechanical of spine and lumbar orthosis are discussed in Chapter 4. Results obtained from the present study are presented graphically and statistically in Chapter 5. Chapter 6 discusses the overall results in greater depth and finally Chapter 7 concludes the dissertation with suggestion of further work.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter begins by briefly describing the structure, function and abnormalities of spine and methods to treat the disorders. Spinal orthoses were explained in the next section. Principles, components, and types of spinal orthoses were described in this section. Subsequently, the previous studies carried out in evaluation and designs of spinal orthoses were reviewed. This section focused on the methods and materials used in order to evaluate and design the particular orthosis. Results from previous studies will be compared to the result of present study whichever applicable.

2.2 Properties of human spine

In skeletal system, human spine consists of vertebral column that extends from the skull to the pelvis which contains 26 bones called vertebrae. The vertebral column is the central bony pillar of the body. It supports the skull, pectoral girdle, upper limbs, and the thoracic cage, and by way of the pelvic girdle, transmits body weight to the lower limbs. Within its cavity lie the spinal cord, the roots of the spinal nerves, and the covering meninges, to which the vertebral column gives great protection (Shelly & Poynton, 2005). There are seven cervical vertebrae, 12 thoracic vertebrae, five lumbar vertebrae, sacrum, and coccyx vertebrae. These vertebrae are separated by pads of intervertebral discs that act as absorbers and allow the column to bend. Lumbar vertebrae have large, heavy bodies because they support most of the body weight and have many back muscles attached to them. Clinically, there are four curvatures that increase the strength and resilience of the column namely cervical curvature, thoracic curvature, lumbar curvature and sacral curvature (Applegate, 2000). Vertebral column is a flexible structure with regional differences but possess a common pattern as shown in Figure 2.1.

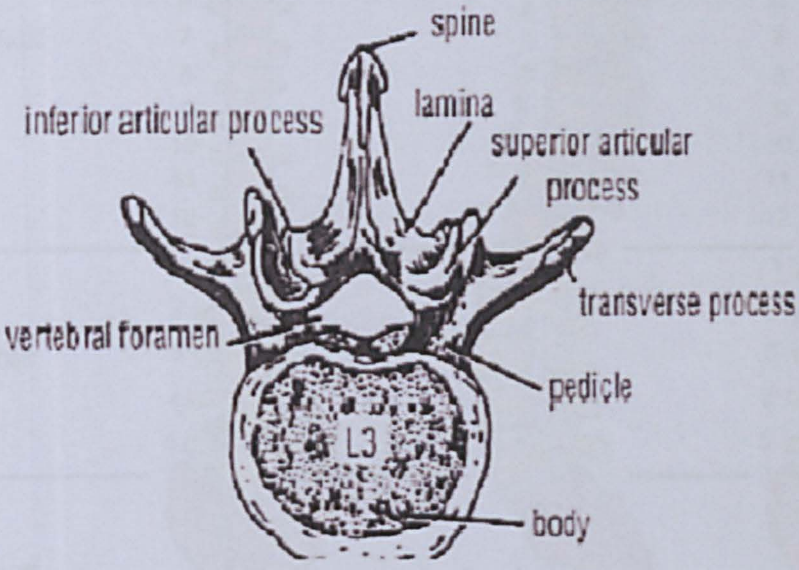


Figure 2.1
Typical vertebrae (Adopted from Shelly & Poynton, 2005)

The multiple spine segments are joined by intervening discs and structurally augmented by connecting ligaments and muscles. The entire spine of anterior, lateral, and posterior views was depicted in Figure 2.2, demonstrating the natural curvature that changes from segment to segment. The lateral view shows the normal lordotic curve found in the cervical and lumbar regions. A kyphotic curve is normal in thoracic and sacral regions. These curves can be modified or accentuated in disease (Mathis, 2003).

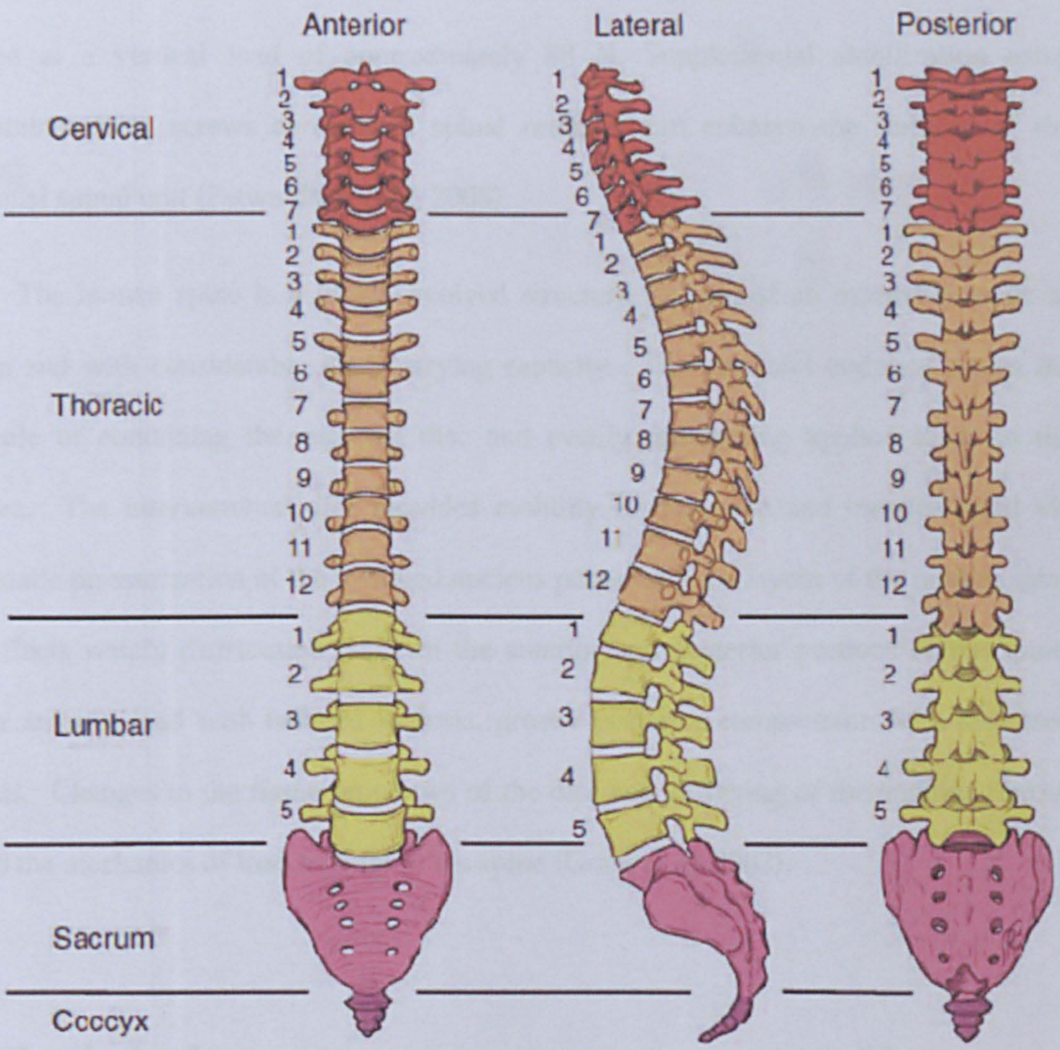


Figure 2.2
Spine structure (Adopted from Mathis, 2003)

In biomechanics perspective, loads on the human spine are shared by osseoligamentous tissues and muscles of the spine. Compressive load on the spine exerted by tensile forces in the paraspinal muscles, balance the moments created by gravitational and external loads. The compressive force on the human lumbar spine is estimated to range from 200 to 300 N during supine and recumbent postures to 1400 N during relaxed standing with the trunk flexed 30°. The stability of spine is characterized by a critical load and when this value is exceeded the spine became unstable and buckled. The lumbar spine buckled at a vertical load of approximately 88 N. Supplemental stabilization using translaminar facet screws or external spinal orthoses can enhance the stability of the functional spinal unit (Patwardhan *et al*, 2008).

The human spine is a highly evolved structure capable of an extensive range of motion and with considerable load carrying capacity. The vertebral endplate serves the dual role of containing the adjacent disc and evenly distributing applied loads to the vertebra. The intervertebral disc provides mobility to the spine and transfers load via hydrostatic pressurization of the hydrated nucleus pulposus. The layout of the lumbar spine also affects weight distribution between the anterior and posterior portions of the spine; greater anterior load with reduced lordosis, greater posterior compression with increased lordosis. Changes to the tissue properties of the disc and stiffening of the annulus fibrous altered the mechanics of load transfer in the spine (Grant *et al*, 2002).

2.3 Low back pain

There are many potential pain generators in the lower back. The discs, facet joints, sacroiliac joint, bones, ligaments, muscles, tendons, and soft tissues can all cause pain (Cooper *et al*, 2008). Low back pain is a major health problem in all developed and developing countries. Low back pain has been related with anthropometric, postural, muscular, and mobility characteristics and the etiologic factors affected by obesity, increased lumbar lordosis, poor abdominal muscle strength, imbalance between flexor and extensor trunk strength, reduced spinal mobility, tight hamstrings, and leg-length inequality (Bayramoglu *et al*, 2001). Although nonspecific low back pain accounts for a very large majority of low back pain, a distinction is made between acute (less than 4 weeks progression), subacute (between 4 weeks and 3 months), and chronic low back pain (more than 3 months) (Calmels *et al*, 2009).

Both acute and chronic low back pains have important societal consequences in terms of health costs, productivity loss due to sick leave and working incapacity. Low back pain was the second most common pain after headache and often affects a variety of physical and psychosocial health domains, from fairly basic self-care activities to advance and complex social interactions, work, and leisure activities (Waddell, 1998). It is also reported that chronic low back pain costs are comparable to those incurred by coronary heart disease, diabetes, or depression (Druss *et al*, 2000). As reported by Andersson (1999), back problems were the most common cause of activity limitation in adults less than 45 years of age and the fourth most common cause in those aged 45-64 years. The lifetime prevalence of time lost from work because low back pain was 34% and 23% respectively. When pain persists for weeks or months, its broader effects on quality of life can be profound. Psychological health and performance of social responsibilities in work and family can be significantly impaired (Gureje *et al*, 1998). Epidemiologic studies have reported that the lifetime prevalence of experiencing low back pain is as high as 80% in the general population (Frymoyer, 1988).

Many cases of low back pain are associated with demonstrable pathologic lesions such as disc herniations or spondylosis. Low back pain that occurs in the absence of an identifiable cause, such as bony injury or disc pathology, is termed nonspecific low back pain (Strenge & Fisk, 2008). Spratt *et al*, (1993) reported that the precise diagnosis is unknown in 80% to 90% of patients presenting with disabling low back pain. Researchers have estimated that only 15% of chronic low back pain cases have an identifiable pathoanatomic explanation (Nachemson *et al*, 1978). The vast majority of non specific low back pain is managed conservatively with rest, analgesics, anti-imflammatory medications, physical therapy, manipulation, and in many cases, orthoses. Lumbar supports continue to be one of the most common methods of handling the impairment and disability caused by low back pain, despite the lack of knowledge regarding their true physiologic effect or their effectiveness in relieving symptoms (Koes & van den Hoogen, 1994).

2.4 Commonly used spinal orthoses

Spinal orthoses have been used as non operative and postoperative devices in the treatment of spinal injuries. When spinal pain impedes functional capabilities, a spinal orthosis may be introduced to reduce the intensity of the pain (Gavin *et al*, 1993). Spinal orthoses are divided into semirigid and rigid orthoses. Semirigid spinal orthoses, known as corsets, can be effective in managing pain due to muscle strain because they reduce the activity of the spinal and abdominal musculature. Examples of corsets are sacroiliac corsets, lumbosacral corsets, and thoracolumbosacral corsets. Sacroiliac corsets provide assistance to the pelvis only. Lumbosacral corsets encompass the pelvis and abdomen, and thoracolumbosacral corsets increase the leverage of the corset system (Romo *et al*, 2008).

Particular type of spinal orthosis is indicated for particular spinal pain. For examples, lumbar support is the most common method of handling the impairment and disability caused by low back pain (Koes & van den Hoogen, 1994). Neck pain has been widely supported by cervical orthosis. This orthosis has become an extremely important component of trauma protocols for safe extrication and transport of traumatized individuals (Strenge & Fisk, 2008). Scoliotic and kyphotic deformities of the spine are also treated by orthoses. However, the use of orthoses in the treatment of these spinal deformities is controversial. Usually, they are used to prevent further progression or to effect mild correction of an existing deformity in a growing child or adolescent (Katz, 2008). With the exception of some fractures of the upper cervical spine and bilateral facet fractures, orthotic treatment of spinal trauma may be prescribed only for clinical stable spinal fracture. These treatments are based on the ideas of immobilization of the fracture to reduce pain and reduction of the deformities associated with particular injuries. Spinal orthoses are also used in postoperative care because they are thought to protect the construct from unwanted external loads that may compromise the healing process (Malas *et al*, 2008).

2.4.1 Cervical orthoses (CO)

Pain management and motion control of cervical spine indicates the use of cervical orthoses. There are several designs of cervical orthoses that offer different levels of stabilization of cervical spine. These devices are identified by the level at which spinal stabilization is sought such as cervical orthosis and cervicothoracic orthosis. There are soft, semirigid, and hard cervical orthoses. Soft cervical orthosis functions as a kinesthetic reminder for the individual to reduce excessive motion (Romo *et al*, 2008). Semirigid and hard cervical orthoses reduce cervical motion in the sagittal plane more than soft cervical orthosis does but still provide little control of lateral flexion and rotation (Gavin *et al*, 2003). Examples of cervical orthoses were depicted in Figure 2.3.

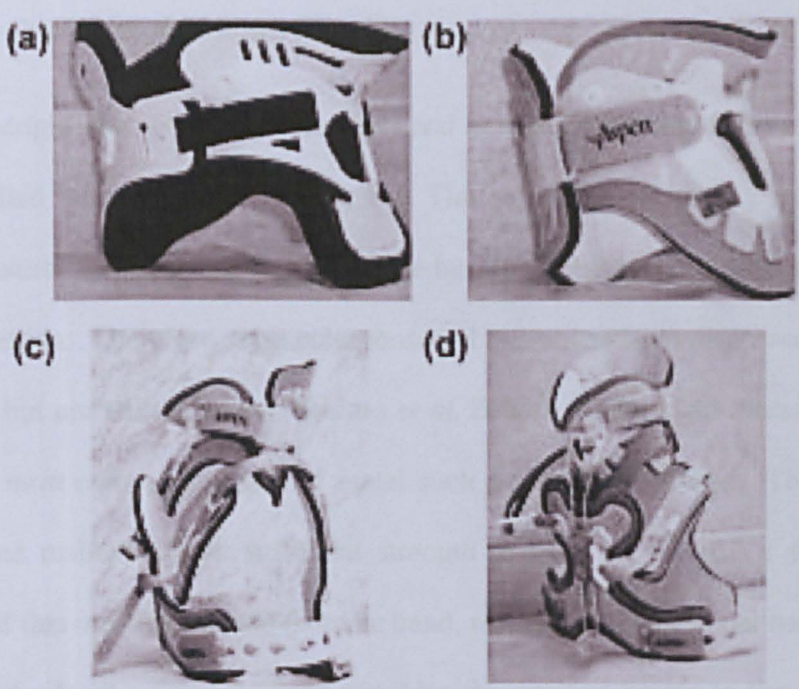


Figure 2.3
Cervical orthoses; (a) Miami J collar, (b) Aspen collar,(c) Aspen 2-post CTO, and (d) Aspen 4-post CTO (Adopted from Gavin *et al*, 2003)

Cervical orthoses can be modified with a thoracic extension to provide more effective stabilization for motion control of the lower cervical spine (Colachis *et al*, 1973). Sternal occipital mandibular immobilizer is one of the examples of cervicothoracic orthoses used for motion control. This orthosis consists of a sternal plate with shoulder components, mandibular pad and bar, and occipital pad and bars that provides good motion control of flexion but allows some extension motion (Johnson, 1977). Another type of these devices is halo cervicothoracic orthosis. This orthosis provides triplanar motion control in the cervical spine. It consists of a halo ring fixed to the skull with pins, a chest jacket, and a superstructure that connects the ring and jacket. This orthosis provides the best endpoint control of the cervical spine and for fracture healing (Benzel, 1989; Triggs, 1993).

2.4.2 Thoracolumbosacral orthoses (TLSO)

There are semirigid and rigid thoracolumbosacral orthosis. Semirigid thoracolumbosacral orthosis is called thoracolumbosacral corset. This corset serves mostly as a kinesthetic reminder to control motion in the thoracic spine but it does not provide sufficient rigidity to prevent the motion. Therefore, thoracolumbosacral corset has been discussed as providing trunk support but not motion control (Romo *et al*, 2008). As for rigid thoracolumbosacral orthosis, it is most commonly made of metal such as aluminum alloys. These alloys are radiolucent and malleable with sufficient strength to hold the orthosis's shape. Basic components of this orthosis include thoracic band, pelvic band, paraspinal bars, lateral bars and interscapular band. Thoracic band provides the greatest height in the midline while allowing for relief of scapulae. Pelvic band increases motion control at the lumbosacral junction (Romo *et al*, 2008). Figure 2.4 showed an example of rigid TLSO.

Figure 2.4
An example of rigid TLSO (Adopted from Mahaudens *et al*, 2008)

Thoracolumbosacral orthosis has been designed according to the motion control required. There are TLSO for flexion control, sagittal control, and triplanar control. Jewett TLSO for flexion control consists of an aluminum frame with pads at the pubis, sternum, and lateral midline of the trunk. Flexion control is achieved through a single three-point pressure system. The system applied two posteriorly directed forces at sternal pad and pubic pad. An equal but opposite force is applied anteriorly from the lumbar pad TLSO for sagittal control provides 2 three-point pressure systems in flexion and extension for the thoracic and lumbar spine (Romo *et al*, 2008). As for triplanar control, the orthosis would limit the motion of right and left rotation of the thoracic spine (Cholewicki *et al*, 2003). TLSOs are indicated for treatment of curves with apices at or below T8 (Gavin *et al*, 1993). Main application of TLSO is for non operative treatment of scoliosis. Orthotic examples of TLSOs are such as Boston brace, Milwaukee brace, Rosenberger orthosis, Miami orthosis, and Lyonnaise orthosis.

2.4.3 Lumbosacral orthoses (LSO)

Similar to TLSOs, lumbosacral orthosis were also classified into semirigid and rigid orthoses. Semirigid LSO or lumbosacral corset encompasses the pelvis and abdomen. This type of orthosis increases intracavitary pressure in the abdomen by exerting circumferential pressure and transmit a semirigid three-point pressure system on the lumbar spine (Romo *et al*, 2008). An example of LSO was depicted in Figure 2.5.

Figure 2.5
An example of LSO (Quick Draw Pro, Aspen Medical Products Inc.,Long Beach, CA, USA) (Adopted from Cholewicki *et al*, 2010)

Although the scientific evidence of the clinical effectiveness of LSO commonly used in the relief of low back pain is controversial (Huynh *et al*, 1998), the use of lumbosacral orthosis increases due to a high satisfaction rate among patients with low back pain (Cholewicki, 2004) who convinced it would restrict the motion, decreased disc pressure and changes in posture (Thoumie *et al*, 1998). According to a study, low back pain constitutes a major public health problem by virtue of its direct socioeconomic impact (Phaner *et al*, 2009). Studies in the late 80's concluded there was eighty percent of the population experiences severe low back pain and the number increases in time (Huynh *et al*, 1998). LSO for sagittal control also known as chairback style is indicated for reduction of gross motion in the sagittal plane including both flexion and extension. The mechanism consists of 2 three-point pressure systems. This orthosis uses preformed anterior and posterior acrylonitrile-butadiene-styrene (ABS) plastic panels lined with soft breathable foam (Romo *et al*, 2008).

The mechanical effectiveness of LSO could result from intersegmental motion restriction, gross motion restriction, or decreased load on the spinal column (Strenge & Fisks, 2008).

2.5 Invasive studies of spinal movements

Most of invasive studies involve radiographic techniques in their protocols. Willner (1984) was studied the characteristics of the horizontal and sagittal curves in patients with progressing idiophatic scoliosis treated with a Boston thoracic flexion brace. The range of scoliosis was determined radiographically according to the Cobb method in a standing, relaxed anterior-posterior position with and without the brace. In this study, a comparison between the radiograph and pantograph techniques was obtained, concerning the range of the kyphosis and the lordosis. Willner concluded that the Boston brace seemed to have approximately the same correction forces acting on the thoracic and lumbar scoliosis (Willner, 1984). Methods for measuring segmental motion from lateral views of the lumbar spine have been described by a number of authors. Frobin *et al* (1996) were measured sagittal plane motion of lumbar vertebrae from lateral radiographic views. They have designed a new measurement method based on the (i) analysis of the imaging of the vertebral contours in central projection with reference to image distortion, (ii) definition of objective landmarks or corners on the image contours related to the three-dimensional shape of vertebrae, and (iii) construction of geometric parameters describing sagittal plane angle and displacement. Results from this study depicted that precision of the measurement of rotational and translational motion of lumbar spine can be enhanced by making allowance for radiographic distortional effects and by minimizing subjective influence in the measurement procedure (Frobin *et al*, 1996).

Computer-assisted measurement technique was also implemented to enhance the reliability of radiographic measurement. Quint *et al* (1997) were developed a method of measuring the degree of spondylolithesis, vertebral body height, intervertebral disc space height, disc space angle, and degree of vertebral body wedging by using easily defined points on standard anterior-posterior (AP) and lateral radiographs of the lumbosacral spine. These researchers used a personal computer and a standard spreadsheet program in their study and the calculations of intra and interobserver variability for the measurement of those parameters showed that the technique is reproducible (Quint *et al*, 1997). In 1998, Huynh *et al* was used anterior-posterior and lateral radiographs of lumbar spine to develop a three-dimensional model to investigate the effects of a lumbosacral orthosis on intervertebral mobility, spinal geometry, and the geometrical deformities of discs. Positions studied were neutral standing, maximal flexion, maximal extension, maximal lateral bending and maximal torsion to the left. Vertebral anatomic landmarks were identified on the radiographs and digitized with a Calcomp system. This study resulted in reducing vertebral mobility and discal deformations at the upper segments and increasing vertebral displacements and discal deformities at the lower levels (Huynh *et al*, 1998).

Flexion-extension of the spine is defined in the sagittal plane which divides the body into right and left halves and can be measured from lateral radiographs (Harvey & Hukins, 1998). Lateral radiographs can be obtained from various x ray modalities such as general x ray, CT scan, MRI and videofluoroscopy. Harvey and Hukins (1998) studied the effects of axial rotation and lateral bending investigated by generating a three-dimensional computer model of two adjacent vertebrae and projecting it on to the sagittal plane. The projected model was measured to allow the effects of out-of-plane movement and errors in reference point placement to be calculated. These researchers demonstrated that even when the better reference point placement scheme (centroids) is used, relative flexion measurement still remains an unreliable quantifier of spinal motion (Harvey & Hukins, 1998). Reference data concerning the geometry of the lumbar spine for various degrees of trunk flexion in Chinese men was established and compared to Caucasian individuals (Chen, 1999a). Geometric data was obtained from lateral radiographs, marked by investigators and digitized using a HyperSpace digitizing system and concluded that no significant interracial differences were found in the geometric data resulted from his study (Chen, 1999a). Another study carried out by Chen in 1999 evaluated the reliability of a new method of measuring lumbar lordosis named Vertebral Centroid method and examined the changes in the lordotic curve from 0° to 90° flexion of the trunk. Lateral radiographs taken from the upright position to a trunk flexion of 90° in the increment of 30° were obtained and measured using Centroid and Cobb techniques. Results from this study stated that the Centroid measurement of lumbar lordosis is more reliable than the Cobb method (Chen, 1999b).

Digitizers and computer calculations were widely implemented in the invasive study of spine movements. Lin *et al* (2001) studied lateral dynamic radiographs to depict the change patterns of intervertebral motion of the cervical spine during flexion, upright, and extension positions. Lateral radiographs were analyzed by digitization and computer calculation resulted in changes of qualitative and quantitative values of intervertebral differences help to define the normal flexibility of the cervical spine (Lin *et al*, 2001). In order to investigate immediate and late changes in shape and balance of the thoracic and lumbar spine and lower rib cage on the frontal plane treated by a TLSO, Korovessis *et al* (2000) used roentgenographic technique. The kyphosis and scoliosis measurement was done by Cobb method. As a conclusion of this study, TLSO treatment stopped progression of scoliosis and reduced the number of patients requiring surgery (Korovessis *et al*, 2000). Active lumbar motion without any support or pelvic restraint was sufficiently reliable for analysis of lumbar flexibility. In a study protocol carried out by Miyasaka *et al*, subjects were asked to perform maximal motion of the lumbar spine. The segmental ranges of motion, segmental flexion, and extension of lumbar spine were calculated using functional radiographs. It was found that greatest segmental flexibility induced by the moderate lumbar motion at the upper segment of spine especially in flexion (Miyasaka *et al*, 2000).

Fully flexion of lumbar spine results in a transfer of load from muscle to passive tissue increasing the risk of injury to ligaments (McGill, 1997). Changes in lumbar lordosis would influence several aspects of spine mechanics and the potential of tissue damage. Investigated by McGill and colleagues (2000), fiber angles of extensor muscles at L3 were documented using high resolution ultrasound during neutral and maximal flexion positions result that anterior shear load on the lumbar spine to be highly related to the risk of a back injury. In this study, analysis of videotape images were done by placing a protractor on the monitor screen (McGill *et al*, 2000). Analysis of lumbar spine motion can improve understanding of instability and related surgical interventions (Lee *et al*, 2002). Functional radiographs are used commonly to assess the segmental disorders of the lumbar spine in clinical practice (Miyasaka *et al*, 2000). Lee *et al* (2002) had developed a new technique for the assessment of lumbar spine motion and validated the technique by comparing the results with the outcome of videofluoroscopy method and the correlation was encouraging (Lee *et al*, 2002). Another study carried out by Gavin *et al* (2003) were analysis three types of commonly used cervical orthoses by implementation of both invasive and non invasive techniques. As for the invasive technique, measurement of cervical intervertebral motion was performed with the use of a videofluoroscopy machine and data obtained was analyzed using digitization and angular calculation methods. It is concluded in the study that each orthosis significantly reduced gross and intervertebral motion of cervical spine in flexion and extension (Gavin *et al*, 2003).

Excessive lordosis has been stated as the major cause of postural pain, facet pain, and radiculopathy (Cailliet, 1995) and has a strong relationship with low back pain. Therefore, Kim and colleagues were investigated the relationship between trunk muscle strength and lumbar lordosis during neutral standing using lateral radiographic films. Sacral angle and lumbar lordosis angle were measured by Cobb method and the analysis was done statistically using SPSS for Windows 8.0. This study suggested that the imbalance between trunk muscles can cause excessive lordosis, possibly a major reason for chronic low back pain (Kim *et al*, 2006). The range of motion (ROM) of the trunk is one of the variables used by the clinician to rate the disability of the back injured patients (Fitzgerald *et al*, 1983). Radiography is traditionally used as the "gold standard" for evaluating low back intersegmental function (Pearcy, 1985). Plain film x-rays were also used to measure lumbar spine and pelvic posture differences between standing and sitting studied by De Carvalho and colleagues. In this study, lumbar lordosis, intervertebral disk angles, lumbosacral angle, lumbosacral lordosis, and sacral tilt were measured using computer software. Data were then analyzed by implementation of Bland-Altman technique. The researchers concluded that reduced flex posture and posterior rotation by lumbar motion segments and pelvis respectively in sitting may result in the prevention of low back pain and injury (De Carvalho *et al*, 2010).

2.6 Non invasive studies of spinal movements

In 1981, Stig Willner from the Department of Orthopaedic Surgery, Malmo General Hospital has developed a spinal pantograph to describe and document the posture of the back in the standing position. The spinal pantograph consists of a pantograph with an arm, mounted at the end of each arm by a low fractioned wheel (Willner, 1981). Results obtained from the apparatus have been compared with the measurement done by x-rays. A comparative study of the range of kyphosis and lordosis measured by x-ray and the spinal pantograph depicted a statistically significant correlation. According to Willner, the advantages of this mechanical device were that it reduced the radiation dosage and can be used for screening and follow up examination of the spine posture. Magnusson *et al* (1996) were studied spine movements during weight lifting while wearing a back support. In their study, effects of a back support on muscle force and on overall trunk load were measured by EMG and stadiometer respectively. Stadiometer has been used previously to measure height loss due to lifting (Magnusson *et al*, 1996). It is concluded that the back support reduced the electromyographic signal in the dorsal muscles and reduced the height loss as measured by stadiometer. The same study was carried out by Minitski *et al* (1998) using 16 light emitting diodes (LED), placed on the skin overlying the spinal column and pelvis. The skin mounted device was used to analyze the coordination of the lumbosacral angle and the trunk inclination during lifting of different loads. Kinematic data were derived from the tracking of markers using an OPTPTRAK system. As stated by the investigators, the basic finding of the study was that the changes of lordosis and trunk inclination were correlated due to systematic coordination of degree of freedom by nervous system (Minitski *et al*, 1998).

Electrogoniometer is another example of non invasive apparatus used in the study of spine movements and effects of spinal orthosis on particular spine posture. Thoumie and colleagues have been determined the effects of lumbar support in lumbar posture and motion during standing and work related activities. In this study, the lumbar spine sagittal kinematics of healthy subjects was assessed with an electrogoniometer with and without wearing a lumbar support. Comparative study with the x-ray measurement technique was also carried out and there was a reasonably correlated result from both techniques. It is confirmed that a lumbar support limits slightly global lumbar motion (Thoumie *et al*, 1998). Electrogoniometer was also integrated in a new lumbar spine motion analysis system developed by Lee *et al* (2002) with a VF unit and a tailor-made image digitizing system. Dynamic lumbar flexion-extension motions were assessed and the results obtained were encouraging. Lee concluded that the developed system may have potential value for evaluating spine instability in clinical practice (Lee *et al*, 2002). Electrogoniometer was also utilized in a study to develop and evaluate the performance of a non-invasive lumbar spine geometry assessment method to predict the position and orientation of the lumbar vertebral bodies in the upright neutral position. The instrument used in the study allows for the accurate representation of the vertebral position and orientation using scaled anthropometric data and individual goniometric measurement (Campbell-Kyureghyan *et al*, 2005).

Computerized dynamic motion analysis devices are also implemented in the biomechanical studies of spinal movements. Mannion and Troke (1999) was compared the ranges of lumbar flexion, extension, lateral bending and axial rotation measured by CA 600 Spine Motion Analyzer and the Polhemus Fastrak system, however the results were controversial and further investigation is crucial (Mannion & Troke, 1999). In other study, angular measures of cervical spinal motion obtained from radiographs and from measures recorded by the OSI CA 6000 Spine Motion Analyzer were compared. The OSI Spinal Motion Analyzer is an apparatus designed to provide measurements of spinal motion in multiple planes of movements simultaneously. The agreement between both measurement methods is poor thus implying that range of motion values taken from the OSI Spinal Motion Analyzer were not similar to those obtained from radiographs for the motions of the cervical spine (Petersen *et al*, 2008).

Gavin *et al* (2003) studied the effects of cervical orthoses in flexion and extension of the head measured by an optoelectronic motion measurement system and emphasized that each orthosis reduced the gross and intervertebral motions of the head. The optoelectronic system provided three dimensional motions of the head analysis in real time (Gavin *et al*, 2003). Mannion *et al* (2004) measured spinal mobility using the Spinal Mouse system, a hand held computer assisted electromechanical device to study spinal curvature in various postures. For global regions of the spine, the system delivered consistent reliable values for standing curvatures and ranges of motion compared with the previous researches (Mannion *et al*, 2004). Vicon 370, a three-dimensional motion analysis system and force platforms were used to collect kinematic and kinetic data during walking in a study to compare the gait pattern of patients with adolescent idiopathic scoliosis managed by the conventional rigid spinal orthosis (Wong *et al*, 2008).

Biomechanical studies on lumbar back supports often use electromyography (EMG) to assess the effect on trunk muscle activities. Jorgensen and Marras (2000) assessed the effect of different controlled lumbar back support tightness levels on trunk muscle activity in trunk extensions at three static submaximal extension moment levels. They concluded that as long as electrodes are protected from direct contact with the back support, studies assessing the effect of lumbar back supports on the trunk muscle via EMG during static tasks are not subject to confounding due to differences in tensions between subjects (Jorgensen & Marras, 2000). Cholewicki *et al* (2003) were measured the spine motion noninvasively with a thin strain gauge device named Flexducer and passive trunk stiffness around the neutral posture was estimated from an electromyography-assisted biomechanical model. The Flexducer consisted of a thin stainless-steel strip with four strain gauges. The signals from all four strain gauges were summed, amplified, and recorded with a 12-bit resolution A/D board at 1600 Hz (Cholewicki *et al*, 2003). In order to assess whole torso and lumbar motions and comfort for each three lumbar orthoses condition during performance of activities of daily living Krag and his colleagues (2003) measured the lumbar motions using a Lordosimeter. The Lordosimeter was taped to the skin along the midline of the lumbosacral region. Lumbar motion was measured inside the orthosis and without modification of it due to the usage of Lordosimeter (Krag *et al*, 2003). An investigation was carried out to evaluate the effect of wearing an elastic lumbar support in the isometric and isokinetic muscle strength of the flexors and extensors of the trunk using a Cybex® 6000 dynamometer with a Trunk Flexion/Extension module (TEF) and no changes were observed (Fayolle-Minon & Calmels, 2008).

2.7 Effects of Spinal Orthoses

Evaluations of spinal orthoses were studied to clarify effects of wearing the orthoses as a prevention or treatment apparatus on the behaviors of spine. As discussed by Magnusson *et al*, 1996 lumbar support assisted subjects in lifting and gave a sense of security and this statement is in agreement to the previous researchers before them.

Immediate height changes with and without support resulted from the study was depicted in Table 2.1.

Table 2.1
Immediate height changes with or without back support (mm, height gain given by a positive number) (Reproduced from Magnusson *et al*, 1996)

	Subject	
	Support off (mm)	Support on (mm)
1	0	-1.28
2	0.63	-0.77
3	-0.81	-0.42
4	0.85	-0.58
5	-1.47	-2.76
6	2.15	-0.71
7	2.29	-0.79
8	Not available	Not available
9	2.4	-1.81
10	2.18	-2.16
11	13.18	-7.01
12	0.29	-1.49

The lift task caused a loss of height but the loss was reduced if the back support was utilized. Effects of wearing lumbar belt in single and continuous reading showed that the lumbar belt decreased the flexion and extension angles as investigated by Thoumie *et al*, 1998. Results from this study were shown in Table 2.2 and Table 2.3.

Table 2.2
Changes in lumbar curve angles and motions: single test flexion and extension (Reproduced from Thoumie *et al*, 1998)

	Maximal flexion	Orthostatic position	Maximal extension	Total flexion/extension RoM
Without belt (SD)	-30° (16°)	34° (12°)	58° (16°)	87° (16°)
With belt (SD)	-25° (18°)	31° (10°)	49° (17°)	74° (8°)
Comparison (ANOVA)	$F = 8.7$	$F = 10.2$	$F = 28$	$F = 42$
	$P = 0.01$	$P < 0.01$	$P < 0.001$	$P < 0.001$

These changes were related to the individual initial values, the highest the initial value the greatest the decrease of the angles.

Table 2.3
Changes in lordosis angles and motions in continuous reading (Reproduced from Thoumie *et al*, 1998)

	Maximal flexion angle	Mean lumbar curve value	Maximal extension angle	Total flexion/extension RoM	Lumbar curve in sitting position
Without belt (SD)	-22° (11°)	21° (11°)	36° (10°)	58° (13°)	-17° (10°)
With belt (SD)	-15° (9°)	17° (9°)	30° (10°)	45° (10°)	-9° (19°)
Comparison (ANOVA)	$F = 83.9$	$F = 6.7$	$F = 10$	$F = 13$	$F = 3$
	$P = 0.07$	$P = 0.02$	$P < 0.01$	$P < 0.01$	$P = 0.1$

These results indicated that wearing a lumbar support would slightly reduced global motion and these changes remain during work-related activities (Thoumie *et al*, 1998). As studied by Cholewicki in 2004, the spine compression force is decreased due to the used of lumbosacral orthosis (LSO) in lifting task as presented in Figure 2.6.

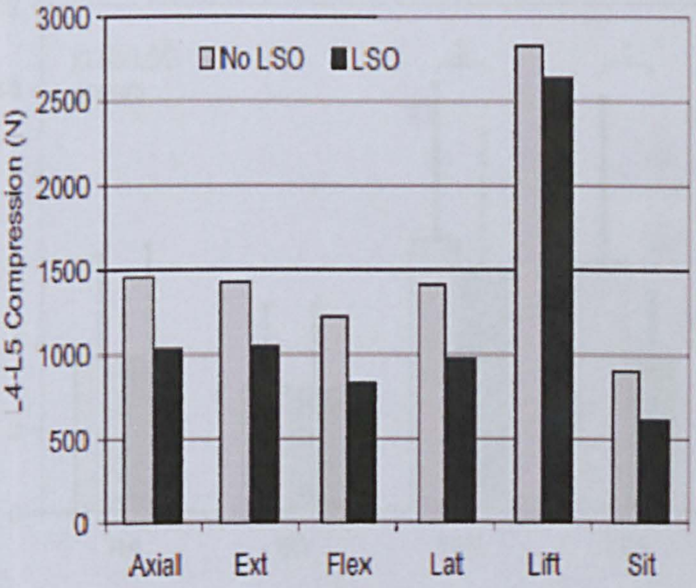


Figure 2.6
The simulated effects of LSO on the spine compression force during various isometric trunk exertions (Adopted from Cholewicki, 2004)

LSO may provide significant symptomatic relief to some low back pain patients by reducing the trunk muscle contraction and preventing muscle fatigue and pain (Cholewicki, 2004). In another study by Cholewicki *et al* (2007), EMG activities were significantly lower in the LSO as compared to the cases without LSO. The result is shown in Figure 2.7.

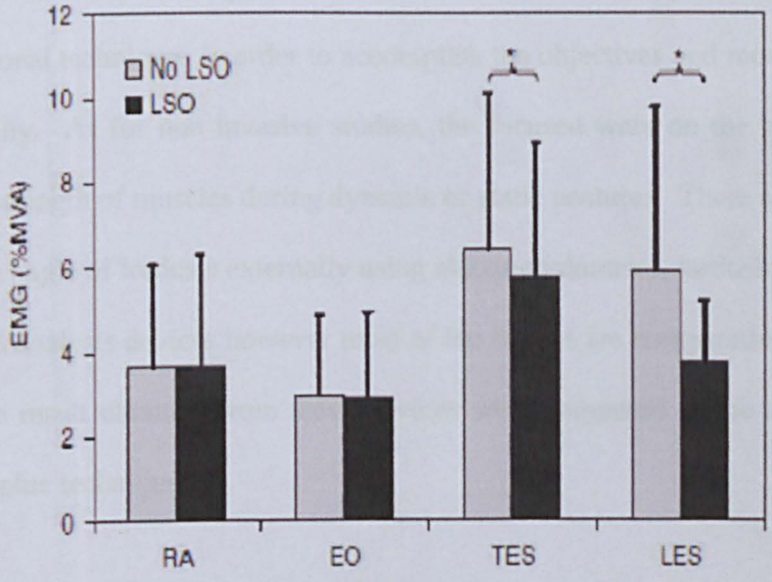


Figure 2.7
Comparison of trunk muscle EMG activity between the LSO and no LSO conditions (Adopted from Cholewicki *et al*, 2007)

Reduction in muscle co-contraction could benefit patients with low back pain who exhibit elevated muscular activity during postural task (Cholewicki *et al*, 2007). Spinal orthoses are proposed widely for therapeutic and prevention options in practice due to the ability in controlling lumbar mobility, relative immobilizing of the lumbar spine, and inducing subjective effects such as heat and continuous stimulation (Calmels *et al*, 2009).

2.8 Summary

In this chapter, the progressing investigation on the spine and the emerging of assessments and evaluation techniques were reviewed. Most of the studies on spinal movements involve radiographic method for measuring lordosis and kyphosis of spine structures. Various experimental designs were developed to achieve the aim of each investigation with and without spinal orthosis. Invasive studies implemented both manual and computational techniques in order to accomplish the objectives and most analysis were done statistically. As for non invasive studies, the focused were on the gross motion of spine and the strength of muscles during dynamic or static postures. There are few attempts to measure the angle of lordosis externally using electrogoniometer, lordosimeter, and skin-surface motion analysis devices however most of the studies are comparative studies which means that the result obtained from these devices were compared to the results obtained using radiographic technique.

CHAPTER 3: METHODOLOGY

3.1 Introduction

Methodology of the present study was discussed in this chapter. Figure 3.1 depicted the flow diagram of the methodology implemented. Each part of the flow diagram will be described in the following section. The chapter begins with the description of subjects involved and type of lumbosacral orthosis used in the experiment. Raw data was obtained radiographically and measurement of lumbar lordosis was carried out using standard techniques applied in clinical practices. Data analysis was explained at the end of the chapter.

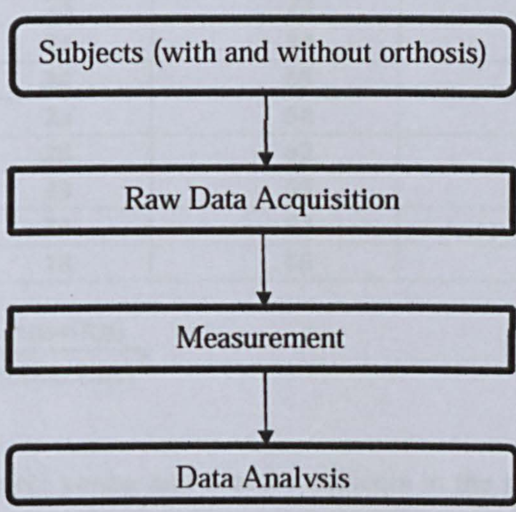


Figure 3.1
Flow diagram of the experimental methods

3.2 Subjects

Ten healthy male subjects without any history of low back pain were recruited. Absence of low back pain would optimize the work and efficiency of the lumbosacral orthosis. Subjects had a mean (SD) age of 22.7 (1.7) years, a mean (SD) height of 1.68 (0.05) m, and a mean (SD) weight of 63.5 (4.48) kg. Body mass index (BMI) of the subjects was also presented. Table 3.1 summarized the information of the subjects involved in the study.

Table 3.1
Details of the subjects

Subject	Age	Weight (kg)	Height (m)	Body Mass Index (BMI)
1	23	64	1.61	24.7
2	23	61	1.69	21.4
3	23	72	1.71	24.6
4	24	54	1.62	20.6
5	24	65	1.62	24.8
6	23	64	1.71	21.9
7	23	62	1.77	19.8
8	23	63	1.67	22.6
9	23	64	1.71	21.9
10	18	66	1.66	24.0

Note: $BMI = \frac{mass(kg)}{(height(m))^2}$

The study deliberately select young and healthy subjects in the age range of 18 to 23 years to eliminate the possibility of any spine injuries that would affect the results. Furthermore, subjects have the ability to perform the movements required by the experiment successfully. Subjects had been interviewed and asked to perform all the required movements. Only successful candidates were recruited. This study was also limited to male subjects because of the ethical concerns of nonmedically indicated radiographs incurred on female subjects (Mannion *et al*, 2004). BMI is a measure of body fats based on height and weight that applies to both adult men and women. Table 3.2 indicated the range of standard BMI and their description.

Table 3.2
Standard BMI and description (Reproduced from Henderson, 2005)

BMI ranges	*Description*
< 18.5	underweight
18.5-24.9	normal weight
25.0-29.9	overweight
≥ 30.0	obese

Different levels of BMI are associated with morbidity and mortality risk levels, and the level of body fat or adipose tissue stored in the body. Evidences showed that, across the populations in time and space, both very low and high levels of BMI were unhealthy and increased the probability of morbidity and mortality (Henderson, 2005). According to Table 3.2, all subjects involved in this study were within the normal weight range.

Each subject was informed of the procedures and risks of this study and was allowed to ask questions or exit the study at any time. Spine x-ray examination is a painless procedure. However, subjects may experience discomfort from the cool temperature in the examination room and may also find holding still in a particular position uncomfortable. No radiation remains in the subjects after the x-ray examination. The dose exposed for spine x-rays is about the same as receiving the background radiation in 6 months. Written informed consent was obtained from each of the subject who agreed to participate. Example of the consent form is presented in Figure 3.2.

I, ...Identity Card No...
(Name of Subject)

of

...
(Address)

hereby agree to take part in the clinical research (clinical study/questionnaire study/drug trial) specified below:

Title of Study: Evaluation of lumbosacral orthosis effects on spinal movements

the nature and purpose of which has been explained to me by researcher;

...
(Name & Designation)

and interpreted by ;..to the best of his/her ability in
(Name & Designation of Interpreter)

... language/dialect.

I have been told about the nature of the clinical research in terms of methodology, possible adverse effects and complications (as per study protocol sheet). After knowing and understanding all the possible advantages and disadvantages of this clinical research, I voluntarily consent of my own free will to participate in the clinical research specified above.

I understand that I can withdraw from this clinical research at any time without assigning any reason whatsoever.

Date: .... **Signature or Thumbprint**

...
(Subject)

IN THE PRESENCE OF

Name ....

Identity Card No. .... **Signature**

...
(Witness)

I confirm that I have explained to the subject the nature and purpose of the above-mentioned research.

Date ....
(researcher)

Figure 3.2
Example of inform consent form filled up by the subjects

The radiographic experimental procedure of this study has been approved by the Medical Ethics Committee of University of Malaya Medical Centre (UMMC), Kuala Lumpur, Malaysia. (Reference no: 763.10).

3.3 Orthosis

A semi-rigid *Dr MED, DR-B026* back brace *LSO* (Jangnim-Dong Saha-Gu, Busan, Korea) were used (Figure 3.3). The orthosis is also known as lumbosacral corset and available in various sizes. The LSO was designed to control the extension and flexion movements of trunk. The back frame of the LSO was made of thermoplastic material to provide support and stabilize the lumbar region. It was also made of combination of light, breathable elastic polyester material for comfort. Polyesters are frequently found in medical applications due to their unique chemical and physical properties. Most of polyesters are highly crystalline with a high melting temperature, hydrophobic, and resistant to hydrolysis (Hai *et al*, 2003). The width of the orthosis was 21 cm in the front and 33 cm at the back.

In exerting circumferential pressure, the LSO increased intracavitary pressure in the abdomen and transmit a semirigid three-point pressure system onto the lumbar spine. The trim lines of the LSO are inferior to the xiphoid process and superior to the pubic symphysis anteriorly and extend between the inferior angle of the scapula and the sacrococcygeal junction posteriorly (Romo *et al*, 2008). The LSO mechanical effectiveness could resulted from intersegmental motion restriction, gross motion restriction, or decreased load on the spinal column. This type of LSO is commonly prescribed clinically to prevent excessive trunk motion to reduce low back pain (Strenge & Fisk, 2008).

Figure 3.3
Dr MED back brace LSO (Jangnim-Dong Saha-Gu, Busan, Korea)

During the experiment, the LSO was custom-fitted to each subject by an experienced orthotist (registered prosthetist & orthotist).

3.4 Data Acquisition

Following consent procedures, the x-ray images were captured at the Department of Biomedical Imaging, UMMC. All radiographic images were taken under identical conditions, using the same x-ray machines and the same type of high quality film plates. There were two x-ray machines; a portable x-ray GE AMX4 to capture the anterior-posterior images of the spine and general x-ray GE MPG 80 to capture images at lateral view. The arrangement of the x-ray machines was carried out using a standard procedure in clinical practice by experienced radiographer to capture anterior-posterior and lateral radiographic images (Figure 3.4). Both x-ray tubes were positioned 100 cm from the target plate at anterior and sagittal plane.

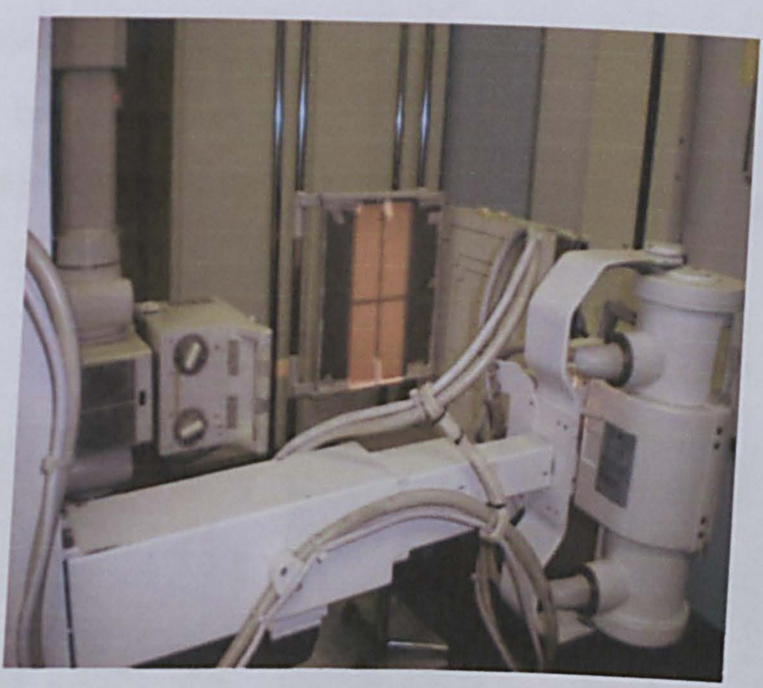
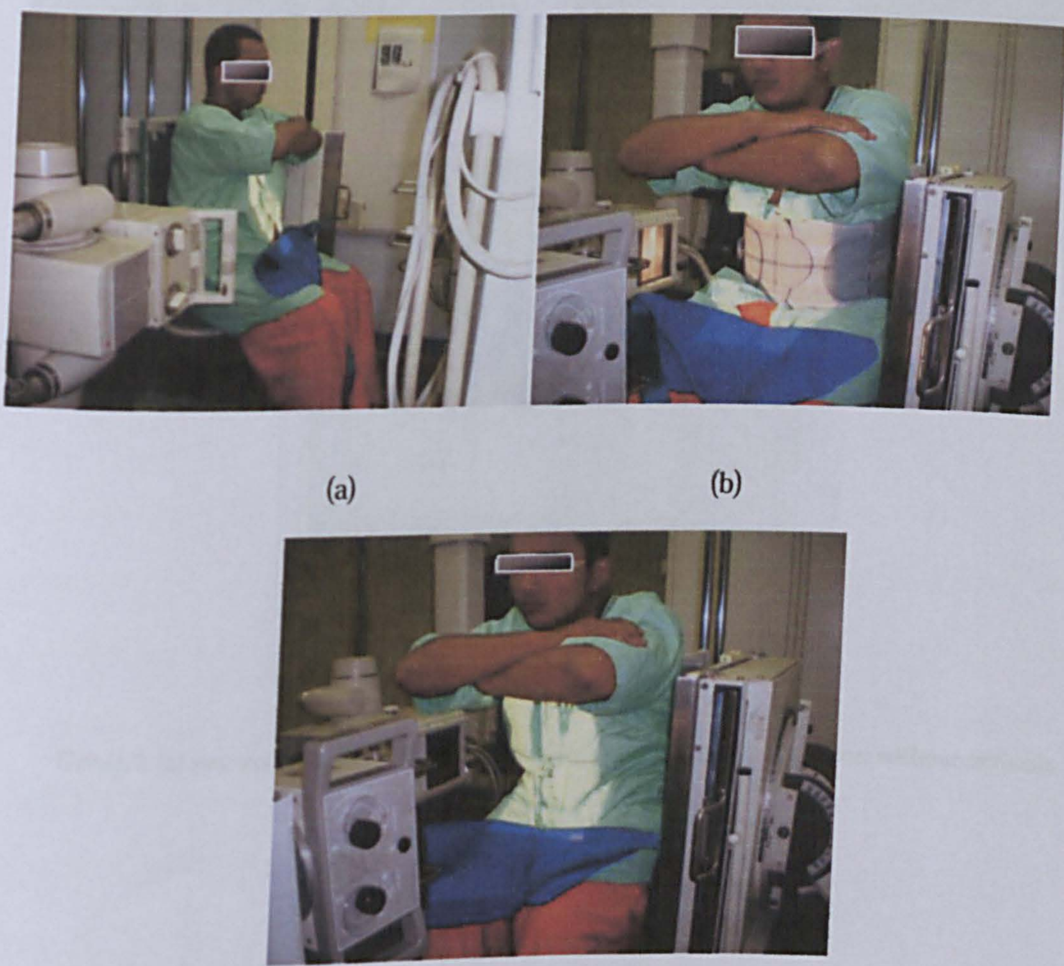


Figure 3.4
Arrangement of the x-ray machines

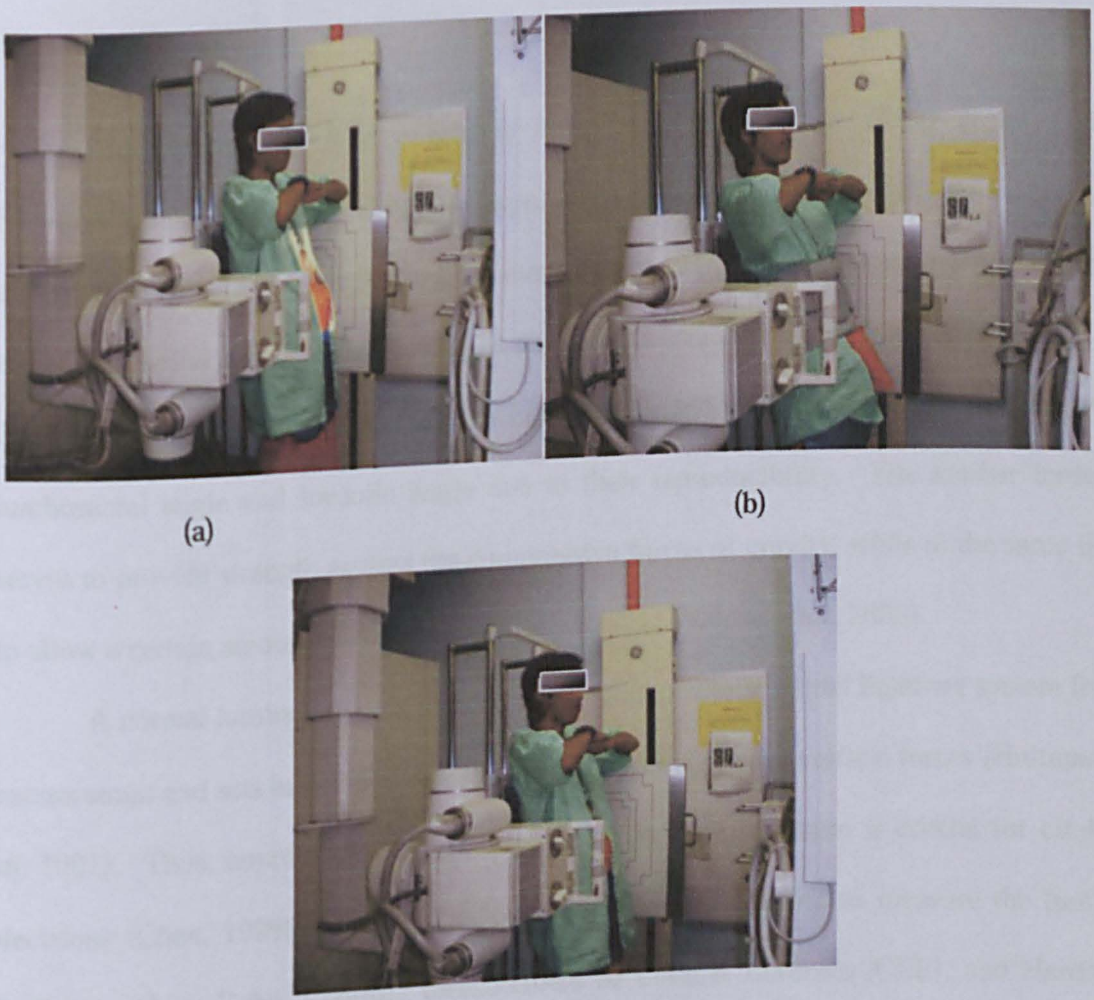
Subjects were divided into two groups, five subjects in Group 1 and another five subjects in Group 2. For Group 1, the anterior-posterior and lateral radiographs of spine images during neutral sitting on an adjustable stool were captured. Feet were flat on the floor and arms folded across the chest (Fritz *et al*, 2005). The same procedures applied to Group 2 except that those subjects in this group were asked to perform the movements in neutral standing with the feet flat on the floor and arms folded across the chest. Fritz *et al* (2005) stated that performing flexion in sitting and extension in standing has been found to produce optimum segmental spinal movements. Subjects sat on an adjustable stool to perform flexion with and without LSO (Group 1), and stood to perform extension with and without orthosis (Group 2). Each subject underwent exposures for six times. Antero-posterior and lateral radiographs images of the spine were captured simultaneously. Subjects were asked to hold very still and to stop breathing for a few seconds while the x-ray picture was taken to reduce the possibility of a blurred image. These x-ray procedures took about 30-40 minutes to complete for each subject. Examples of photos of subjects who underwent the procedure in Group 1 and Group 2 are depicted in Figure 3.5 and Figure 3.6 respectively.



(a) (b) (c)

Figure 3.5

Group 1 (a) neutral sitting, (b) flexion with orthosis, and (c) flexion without orthosis



(a) (b)

(c)

Figure 3.6

Group 2 (a) neutral standing, (b) extension with orthosis, and (c) extension without orthosis

3.5 Measurement

Most studies of lumbar motion have been radiographic (Krag *et al*, 2003). However, due to excessive radiograph exposure, comparisons between orthoses or between different postures have been limited. A simple set of lateral and anterior-posterior views of the lumbar spine can provide significant data on the structure of the bony elements of the lumbar spine (Patel, 2004). Phaner *et al* (2009) adopted a radiographic study to measure lumbosacral angle and lordotic angle due to their reproducibility. The lumbar lordosis serves to provide strength against the compressive forces of gravity, while at the same time to allow a certain amount of flexibility for locomotion (Morningstar, 2003).

A normal lumbar lordosis protects the lumbar posterior spinal ligament system from excess strain and acts as a shock absorber during sudden applied vertical forces (Hultman *et al*, 1992). Thus, appropriate measurement of the lumbar curvature is crucial for clinical decisions (Chen, 1999b). Several methods have been developed to measure the lumbar lordosis such as Cobb, Centroid measurement of Lumbar Lordosis (CLL), and Harrison Posterior Tangent method (Harrison *et al*, 2001). The Cobb angle analysis has been the method of choice for measurement of overall lordosis and kyphosis of the sagittal spinal curves on the lateral radiographs (Harrison *et al*, 2000) and has been for years the gold standard of spinal orthosis efficacy (Smith, 2003).

3.5.1 Cobb method

In Cobb technique, the lumbar lordosis angle was determined by implementing four lines Cobb technique on each of printed lateral radiographic images (Figure 3.7).

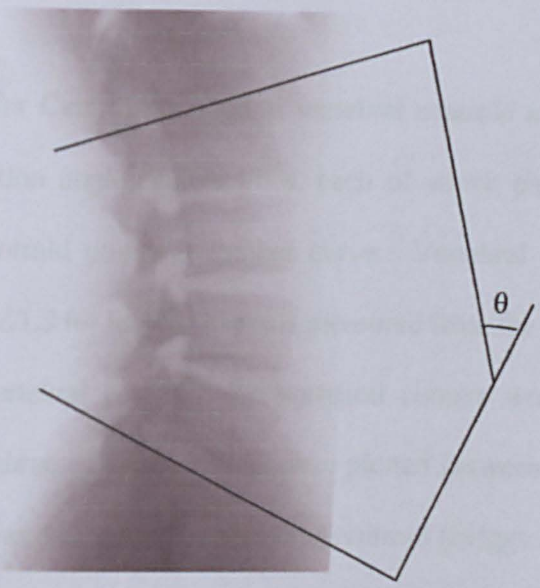


Figure 3.7
Four lines Cobb method on sagittal radiographic view

Lordotic angle was obtained between superior endplate of S1 and inferior endplate of L1 in the lateral view. The four-line Cobb method applied is created by two lines on endplates of different vertebrae; to each line, a perpendicular is drawn so that the perpendiculars intersect (Harrison *et al*, 2000). Angle was measured at the intersection using a protractor. The Cobb method was adopted by the Scoliosis Research Society as the standard method for quantification of scoliotic deformity at the coronal plane. The method is also used for measurement of the curve at the sagittal (lateral) plane (Diab *et al*, 1995). The Cobb technique is the most widely used technique to evaluate the thoracic kyphosis (TK) and lumbar lordosis (LL) from sagittal radiographs (Mac Thiong *et al*, 2007). The Cobb angle predominantly reflects endplate tilt of vertebrae between selected limits of the curve, and therefore may not reveal changes regionally within the curve, nor true intervertebral curvature relative to vertical. Difficulty in accurately identifying the endplate has been reported to be treated to the satisfactory reliability of the Cobb method (Briggs *et al*, 2007).

3.5.2 Centroid method

As for Centroid method, a vertebral centroid angle was determined by measuring the intersection angle of two lines, each of which passed through a pair of contiguous vertebral centroid points at lumbar curve. Vertebral centroid positions were located at L5/S1 and L2/L3 for lumbar lordosis measured from the lateral radiograph (Figure 3.8). To locate the vertebral centroid, the vertebral corners were marked as reference points at selected vertebrae. Diagonal lines were plotted between corner reference points and their intersection was defined as the vertebral centroid (Briggs *et al*, 2007).

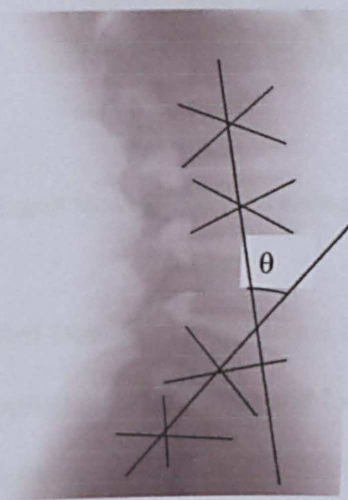


Figure 3.8

Four segments centroid angle method on sagittal radiographic view

3.5.3 Posterior tangent method

The posterior tangent method used the superior-posterior and inferior-posterior body corners (Figure 3.9). Two parallel lines were drawn at the superior-posterior (L1/L2) and inferior-posterior (L5/S1) respectively to be intersected. The intersection angle was measured using a protractor (Harrison *et al*, 2001).

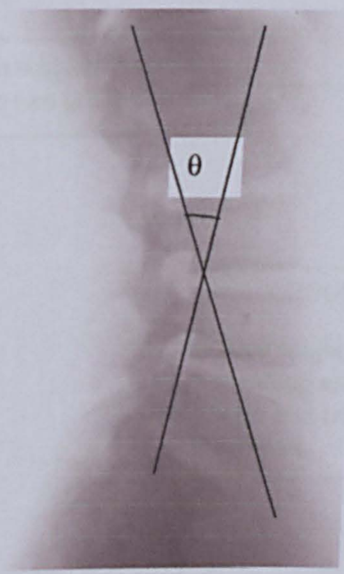


Figure 3.9

Posterior Tangent method on sagittal radiographic view

All the above methods were adapted from the study carried out by Harrison *et al* (2001). Hand drawn line technique was applied on each image and lordotic angles were measured by protractor and the lines were drawn using a ruler (Smith, 2003; Harrison *et al*, 2004). Five observers independently evaluated each radiographic image to determine the angles given by each method. Four observers are radiographers from the Department of Biomedical Imaging, UMMC and another one is the author from the Department of Biomedical Engineering, UM. The observers were allowed to determine the lumbar landmarks on each radiographic image using their own judgment, no hint or instruction was given (Chen, 1999b). The anterior-posterior film was used to exclude any lumbar spine deformities (Lin *et al*, 2001).

3.6 Data Analysis

Management of subjects and experimental data was summarized in Figure 3.10.

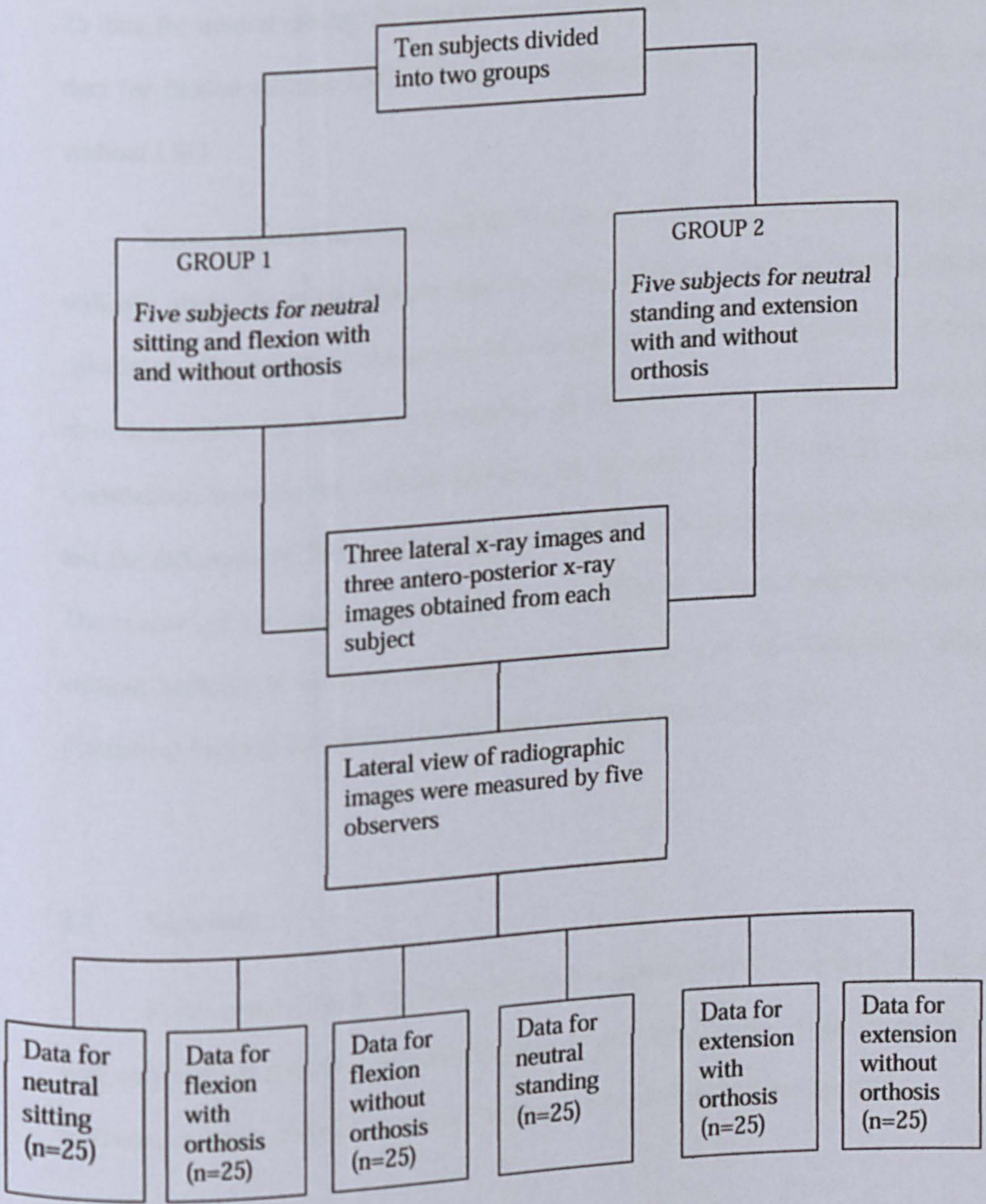


Figure 3.10

Management of subjects and experimental data

Six times exposures to each subject indicated three lateral views and three antero-posterior views of radiographic images. Only lateral views were measured to obtain data for analysis. Each lateral view of each subject was measured by five observers thus there were 25 data for neutral sitting, 25 data for neutral standing, 25 data for flexion with LSO, 25 data for flexion without LSO, 25 data for extension with LSO and 25 data for extension without LSO.

Mean, standard deviation and BMI of braced (with orthosis) and unbraced (without orthosis) trials for trunk flexion and extension obtained from the three methods were calculated. Percentage of changes in flexion and extension with and without orthosis were also determined for better understanding of the effects of lumbosacral orthosis used. Correlations between the methods and analysis of variance (ANOVA) were carried out to test the difference in flexion and extension with and without orthosis in different subjects. The analysis of variance was applied to test the difference in flexion and extension with and without orthosis in different methods. Statistical analysis was completed using SPSS (Statistical Package for the Social Sciences) for Windows version 17.0.

3.7 Summary

In the present study, methods included acquisition of x-ray images of ten subjects with and without orthosis, data measurement using Cobb, Centroid, and Posterior Tangent methods, and data analysis using the computer software, SPSS were discussed.

CHAPTER 4: THEORETICAL ANALYSIS

4.1 Introduction

This chapter attempts to brief on the theoretical analysis of spinal column and lumbar orthoses in different perspective studied by other researchers. A few biomechanical theories related to the study are presented.

4.2 Study designs in lumbar orthoses

Many ways for evaluations of lumbosacral orthoses or abdominal belts have been designed. Miyamoto *et al* (1999) have evaluated the effects of abdominal belts on lifting performance, muscle activation, intra abdominal pressure, and intra muscular pressure of the erector spinae muscles using LIDO Lift system (Loredan Biomedical, Davis, CA, USA). Effects of semi-rigid lumbosacral orthosis use on oxygen consumption during repetitive stoop and squat lifting was also investigated (Duplessis *et al*, 1998). Cholewicki and his research group had evaluated lumbosacral orthoses in many of their studies. Some of the studies were designed to address the spine stabilizing function of LSOs in postural tasks, theoretically estimate the reduction in trunk muscle activation and to compare the trunk stiffness provided by different design characteristics of LSOs (Cholewicki, 2004; Cholewicki *et al*, 2007; Cholewicki *et al*, 2010). Clinical study was also carried out to assess the effectiveness of the lumbar belt in the treatment of patients suffering from subacute low back pain (Calmels *et al*, 2009). Studies of lumbosacral orthoses were commonly performed in particular motion such as flexion and extension of the trunk. Measurement methods involved using a Lordosimeter (Krag *et al*, 2003), electrogoniometer (McNair & Heine, 1999; Thoumie *et al*, 1998) motion analysis systems (Cholewicki *et al*, 2007; Jorgensen & Marras, 2000; Miyamoto *et al*, 1999), dynamometer (Calmels *et al*, 2009; Fayolle-Minon & Calmels, 2008), inclinometer (Ng *et al*, 2001) and radiographic (Huynh *et al*, 1998; Kim *et al*, 2006; Thoumie *et al*, 1998). Researchers concluded that lumbar supports reduce trunk motion with respect to flexion, extension, and lateral bending but provide no significant effect on rotation (Strenge & Fisk, 2008).

4.3 Biomechanics of spine

Forces and moments in different directions that act on the spine can be resolved into the basic loads. These are compressive and tensile forces acting along the long axis of the spine, anteroposterior and mediolateral shearing forces that directly displace the vertebrae in these directions, sagittal plane bending causing flexion or extension, lateral bending, and torsion or rotation about the longitudinal axis of the spine (Cotler *et al*, 2000). The spine exhibits viscoelastic behavior and under load, a spinal motion segment which consists of two vertebrae and interconnecting soft tissues, displaces in a characteristic way. The motion segment has a neutral zone where it can be displaced with little force. Beyond the neutral zone, as the tensions in the tissues increases, is an elastic zone where increasing force is required to produce greater displacement in any direction. When the failure zone is reached, tissue is tore and bony fracture resulted. Release of the applied load after loading into the damage region resulting the motion segment. It is remained in a deformed position because of tissue damage (Shelly & Poynton, 2005). This phenomenon was shown graphically in Figure 4.1.

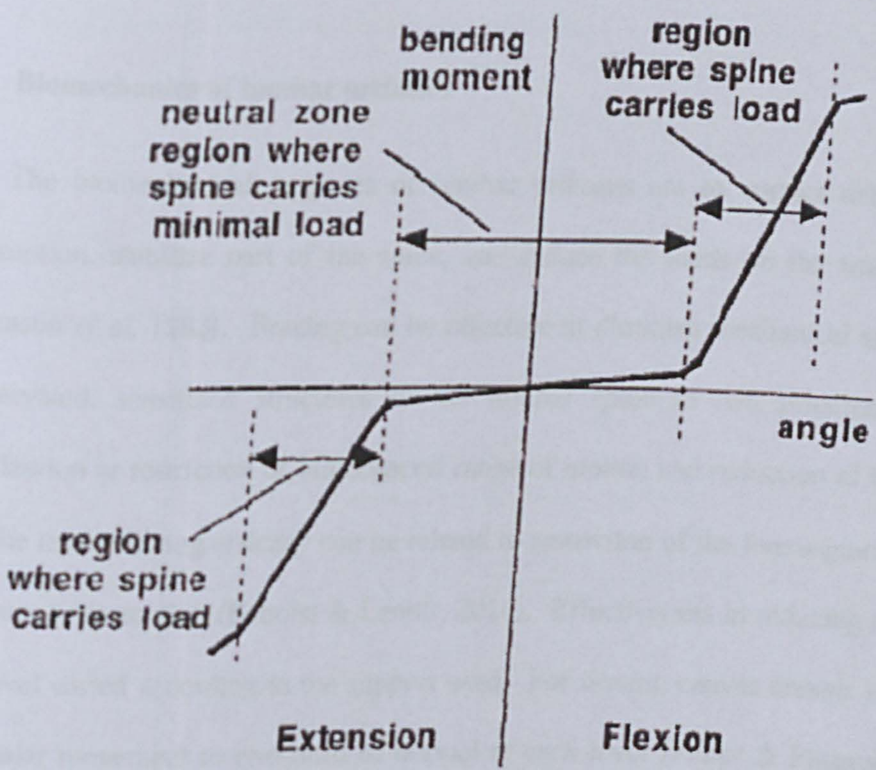


Figure 4.1

Load displacement behavior of a spinal motion segment (Reproduced from Shelly & Poynton, 2005)

The vertebrae increase in size distally, with the lumbar vertebrae being the largest. In between each vertebra is an intervertebral disc that acts as a shock absorber. The lumbar functional unit transmits loads from one vertebra to the next and allows flexion-extension movements to take place, provide stability, and prevent translator and torsional shear. 75% of lumbar flexion and extension occurs at the lumbosacral spine, 20% at L4-L5, and 5% at the other levels (Cooper *et al*, 2008). The functional range of motion varies among individuals and decreases with age. Lumbar motion is maximum in the sagittal flexion-extension plane. The first 50° - 60° of trunk flexion comes from the lumbar spine. Forward tilting of the pelvis provides the additional 20° to 30° (Farfan, 1975).

4.4 Biomechanics of lumbar orthoses

The biomechanical purposes of lumbar orthoses are to correct deformity, limit spinal motion, stabilize part of the spine, and reduce the loads on the trunk structures (Nachemson *et al*, 1983). Bracing can be effective to diminish mechanical stimulation of the innervated, sensitized structures of the lumbar spine in two principal ways, (a) immobilization or restriction of lumbosacral range of motion and reduction of back muscle force. The immobilizing efficacy can be related to restriction of the intersegmental motion and of gross body motion (Benoist & Lenoir, 2010). Effectiveness in reducing movements at each level varied according to the support used. For instant, canvas corsets reduced the mean angular movement to two-third of normal at each level (Fidler & Plasmans, 1983). Nachemson *et al* (1983) assumed that gross motion restriction is more important than reduction in the intersegmental motion. When the upper spine is in flexion, extension, or lateral bending, heavy loads are applied to the trunk. It has also been shown that to immobilize the lumbosacral junction thoroughly, it is imperative to include at least one thigh in the lumbar support (Norton & Brown, 1957).

Another mechanism for orthoses to decrease the risk of low back pain related to a reduction of back muscle force. This could be theoretically be obtained by an increase of abdominal pressure without a concomitant augmentation of abdominal muscle activity. The raised abdominal pressure tends to extend and elongate the spine. By doing so, the lumbar lordosis is straightened and the force required in extensor musculature is reduced, thus relieving the compressive loads off the spine (Bartelink, 1957).

4.5 Quantitative evaluation of spinal curvature

Quantitative evaluation of spinal curvature is valuable for planning of orthopedical surgical procedures, monitoring the progression and treatment of spinal deformities, and for determining reference values in normal and pathological conditions (Vrtovec *et al*, 2009). Table 4.1 depicted degrees of automation, assigned to quantitative evaluation methods.

Table 4.1
Degrees of automation (Adopted from Vrtovec *et al*, 2009)

Degree	Description
0	Visual inspection: such an approach is subjective, unreliable and inconsistent for quantitative evaluation
1	Manual measurement: the observer evaluates the relationship between the manually identified geometrical constructs in the image (i.e., the "ruler and pencil" approach)
2	Computer-assisted measurement: the computer evaluates the relationship between the geometrical constructs, obtained by digital reconstruction of manually identified anatomical landmarks
3	Computerized image processing: the computer evaluates the relationship between the geometrical constructs, obtained or enhances by image processing techniques (e.g., edge detection, filtering)
4	Computerized image analysis: the computer evaluates the relationship between the geometrical constructs, obtained by image analysis techniques (e.g., segmentation, registration)
5	Computerized image understanding: such an approach results in an automated diagnosis, which is the primary objective when developing automated methods

A single quantitative measurement of a spine parameter depends on the unknown true value, the inability of the observer or method to repeat multiple measurements and the bias of the observer or method implemented. Previous researchers used different statistical measures for intra and inter observer variability measurements. Table 4.2 indicated statistical measures for intra-and/or inter-observer variability of the measurement methods.

Table 4.2
Statistical measures for intra-and/or inter-observer variability of the methods (Adapted from Vrtovec *et al*, 2009)

Measure	Description	Definition
Standard deviation	The estimated precision of the measurements	$SD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(m_{i} - \bar{m})}$
Correlation coefficient	The strength of a linear relationship between two sets of measurements	$R = \frac{\sum_{i=1}^{N}(m_i - \bar{m})(n_i - \bar{n})}{\sqrt{\sum_{i=1}^{N}(m_i - \bar{m})^2 \sum_{i=1}^{N}(n_i - \bar{n})^2}}$

Note: N *number of* measurement,
m_i ,n_i *measurement values,*
$\bar{m}, \bar{n}$ *mean measuremet values,*

The evaluation of spinal curvature in the sagittal (lateral) plane referred to the measurement of cervical lordosis, thoracic kyphosis and lumbar lordosis, and to the segmental and reciprocal angulation (Vrtovec *et al*, 2009).

4.6 Summary

The theoretical analysis presented in this chapter will be further discussed in Chapters 5 and 6 of this dissertation.

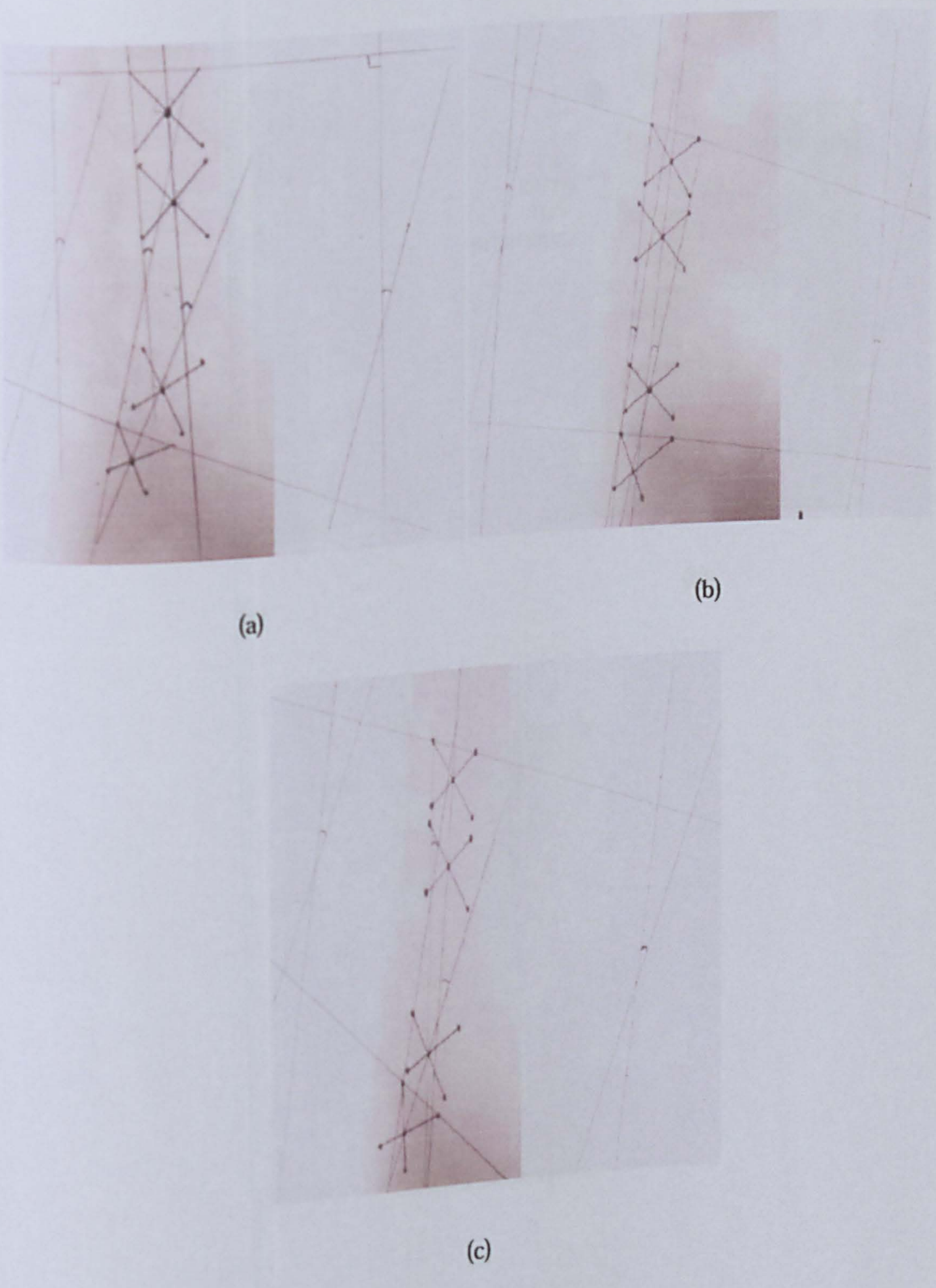
CHAPTER 5: RESULTS

5.1 Introduction

This chapter contained the results and data analysis presented in the form of text, figures, and tables derived from the experiments. Results were focused on the behaviors of spine in flexion and extension postures with and without wearing the lumbosacral orthosis.

5.2 Measurement of Lumbar Lordosis

Techniques implemented in the measurement of lumbar lordosis carried out by an observer for each subject were virtually depicted in Figures 5.1 - 5.10. According to the measurement for Cobb method, angles obtained from anterior or posterior intersection would give the same value.



(a)

(b)

(c)

Figure 5.1

Example of measurement of lumbar lordosis using Cobb, centroid and posterior tangent for subject 1 during (a) neutral sitting, (b) flexion without LSO, and (c) flexion with LSO

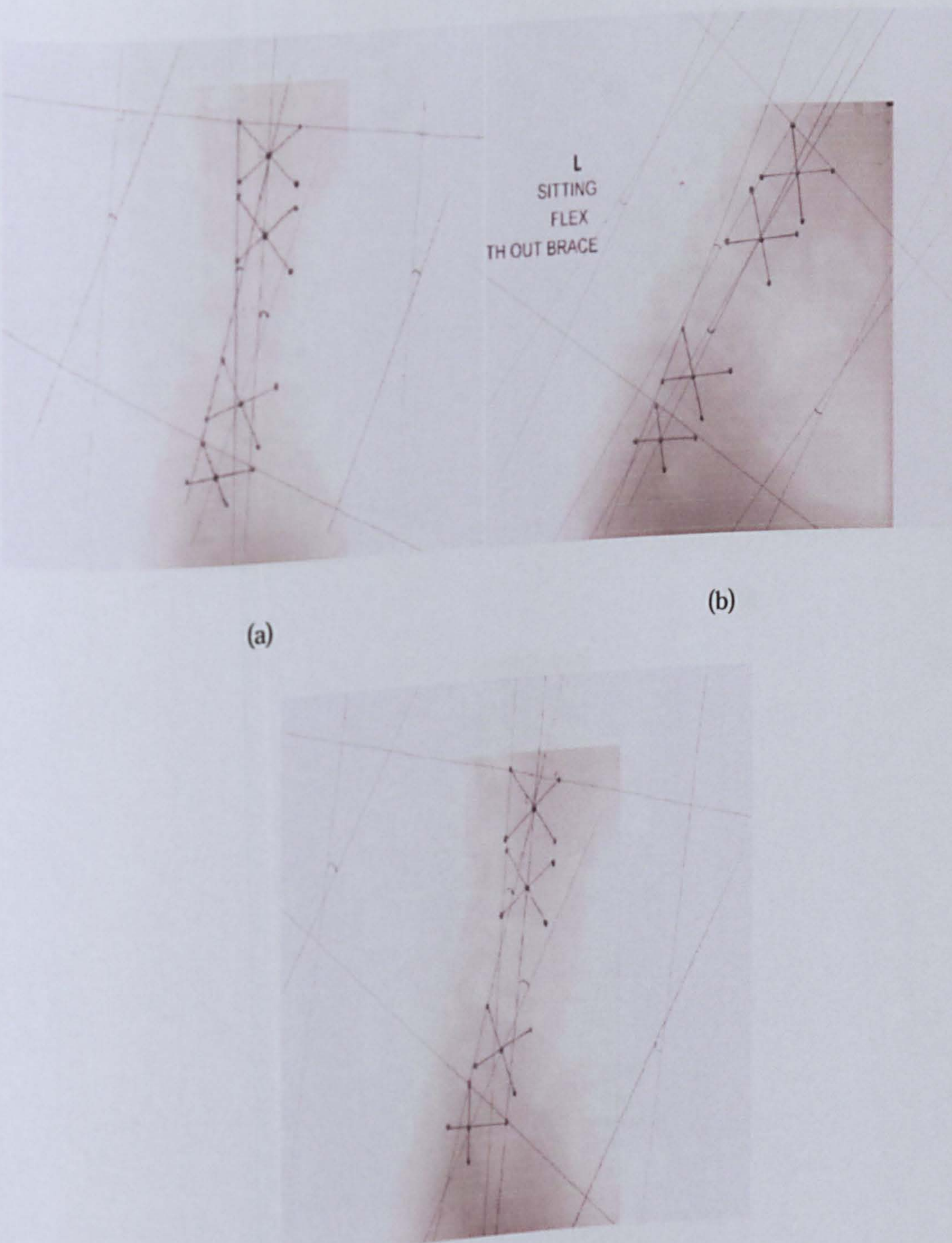
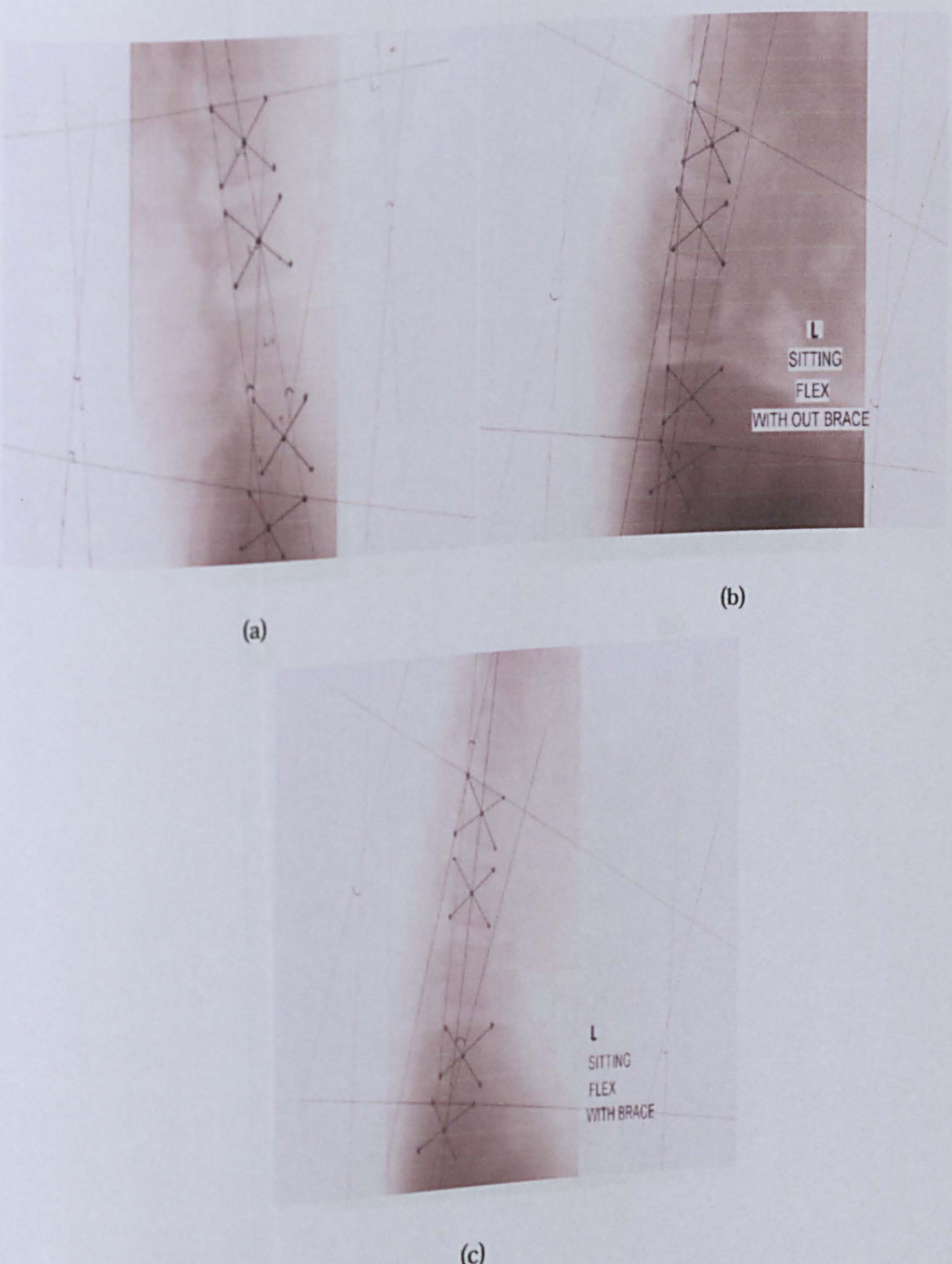


Figure 5.2

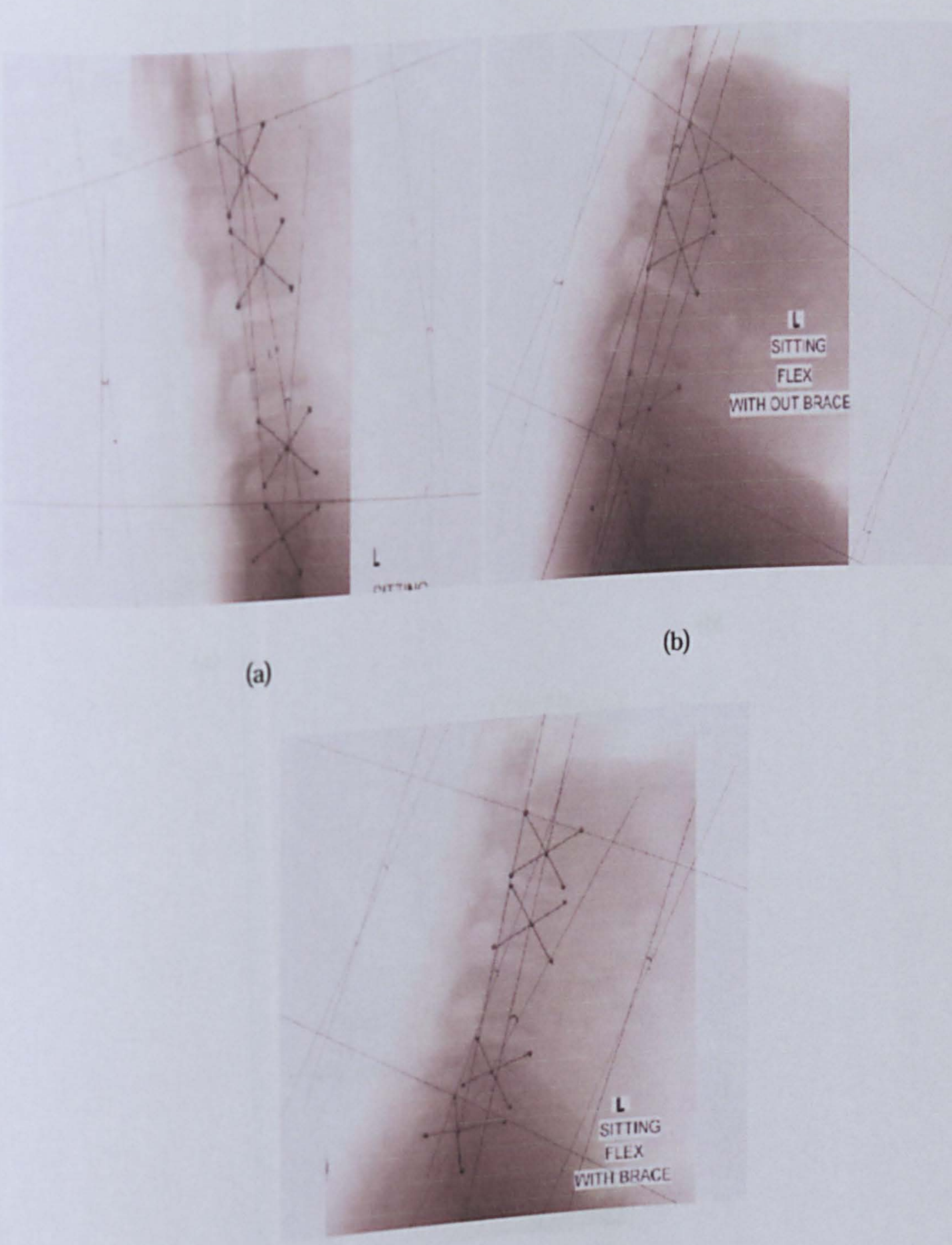
Example of measurement of lumbar lordosis using Cobb, centroid and posterior tangent for subject 2 during (a) neutral sitting, (b) flexion without LSO, and (c) flexion with LSO



(a) (b) (c)

Figure 5.3

Example of measurement of lumbar lordosis using Cobb, centroid and posterior tangent for subject 3 during (a) neutral sitting, (b) flexion without LSO, and (c) flexion with LSO

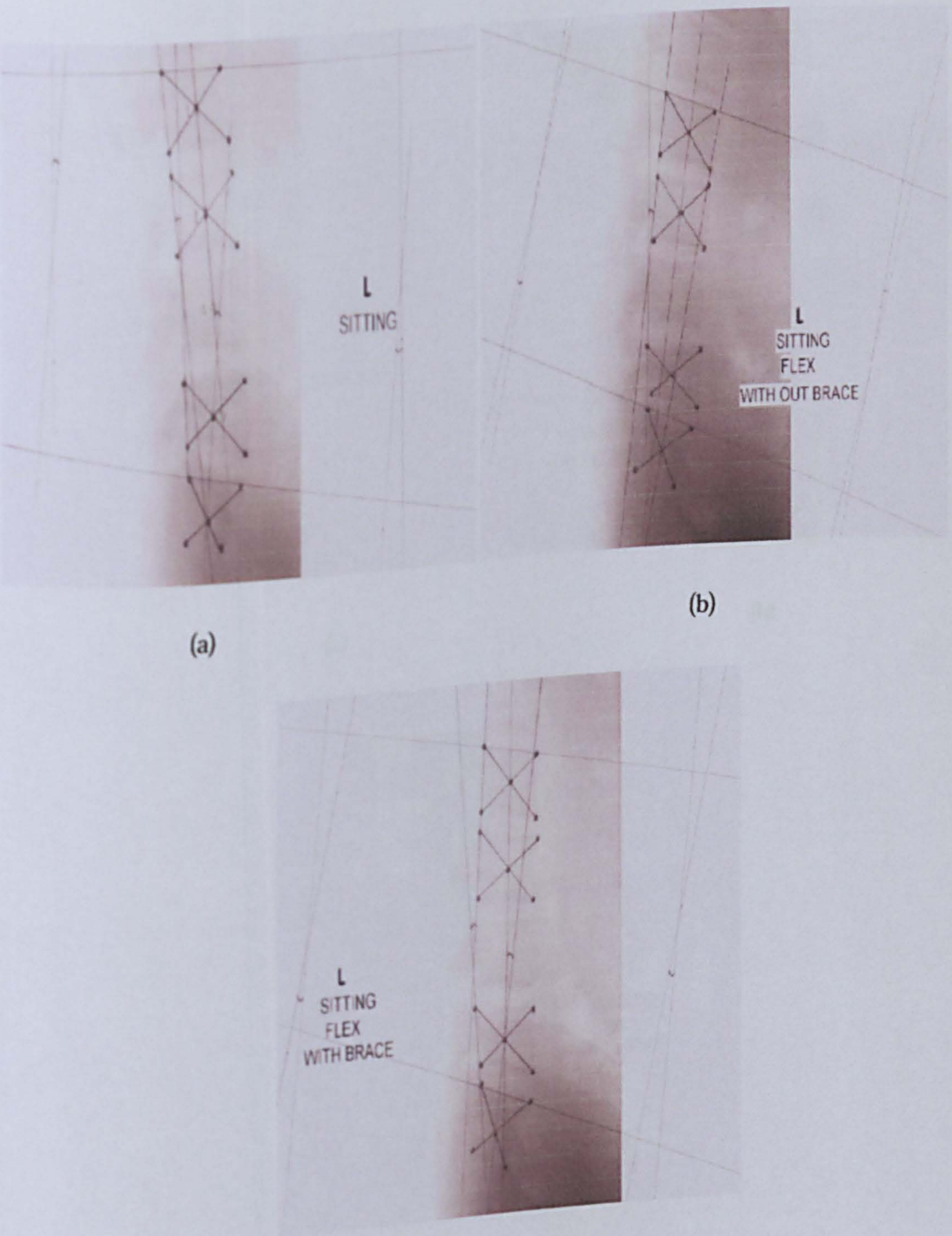


(a) (b)

(c)

Figure 5.4

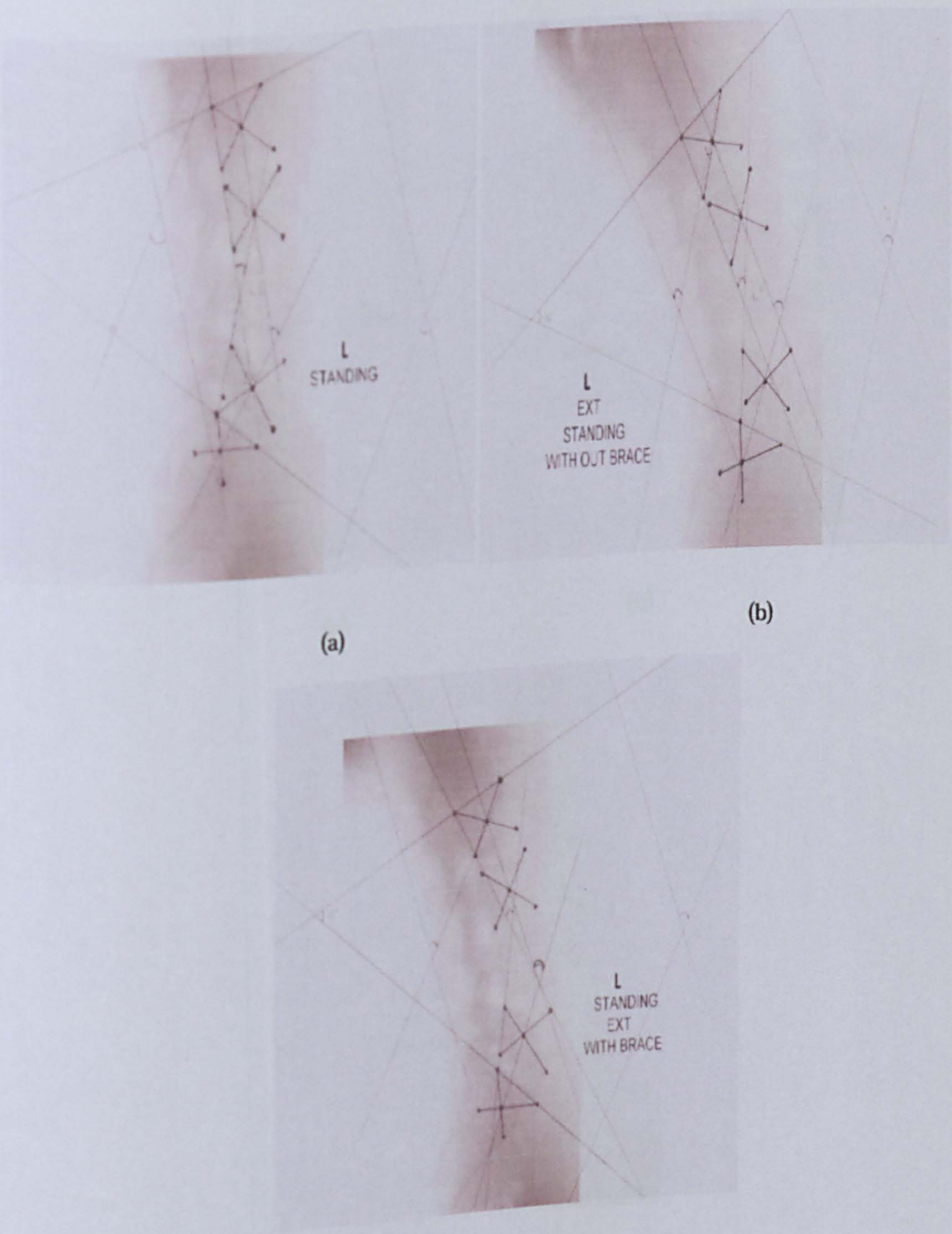
Example of measurement of lumbar lordosis using Cobb, centroid and posterior tangent for subject 4 during (a) neutral sitting, (b) flexion without LSO, and (c) flexion with LSO



(a) (b) (c)

Figure 5.5

Example of measurement of lumbar lordosis using Cobb, centroid and posterior tangent for subject 5 during (a) neutral sitting, (b) flexion without LSO, and (c) flexion with LSO



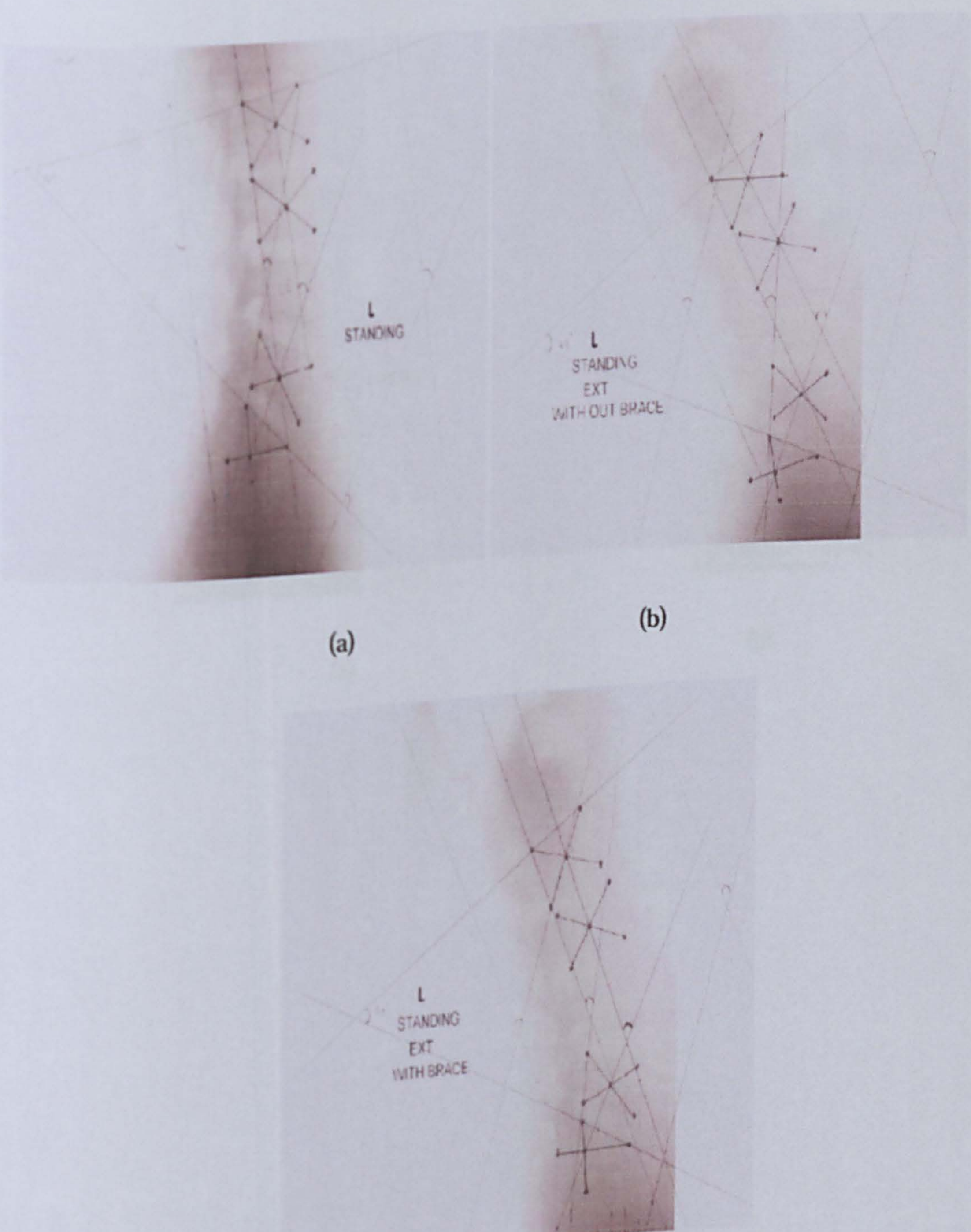
(a)

(b)

(c)

Figure 5.6

Example of measurement of lumbar lordosis using Cobb, centroid and posterior tangent for subject 6 during (a) neutral standing, (b) extension without LSO, and (c) extension with LSO

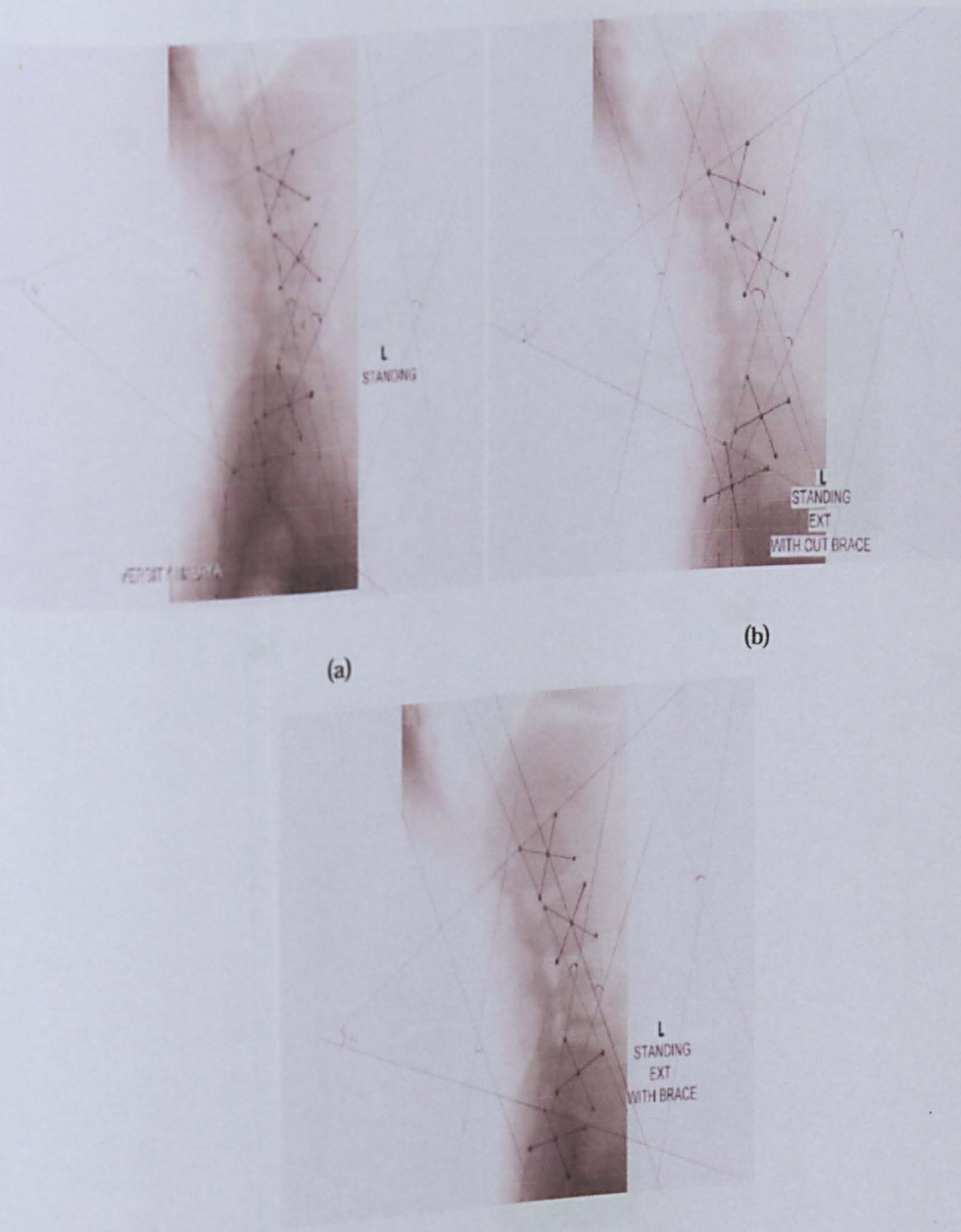


(a) (b)

(c)

Figure 5.7

Example of measurement of lumbar lordosis using Cobb, centroid and posterior tangent for subject 7 during (a) neutral standing, (b) extension without LSO, and (c) extension with LSO

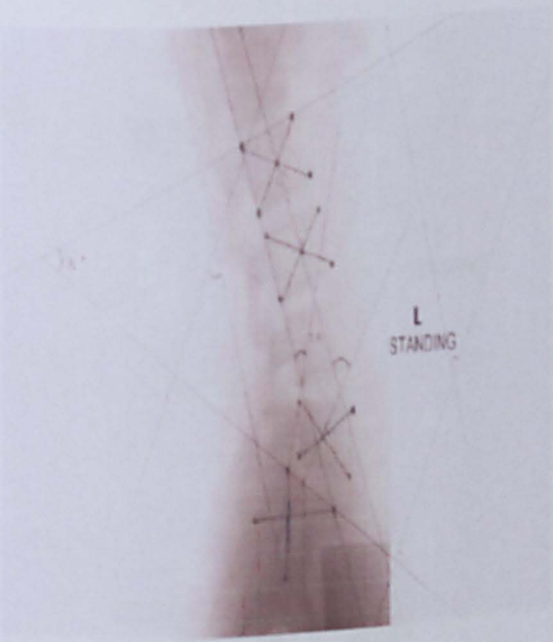


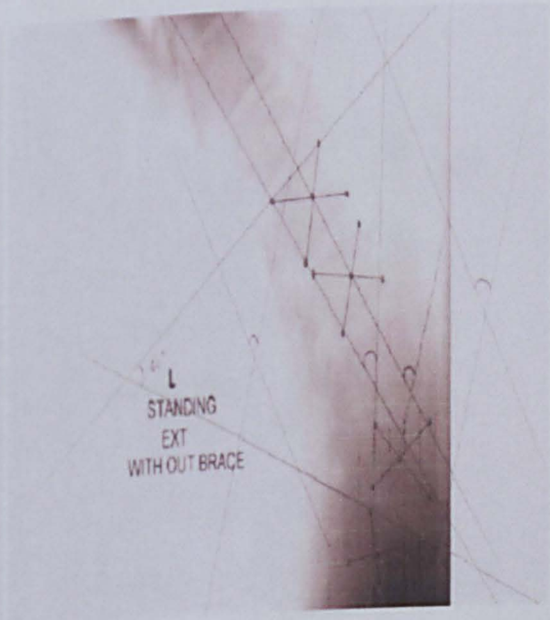
(a) (b)

(c)

Figure 5.8

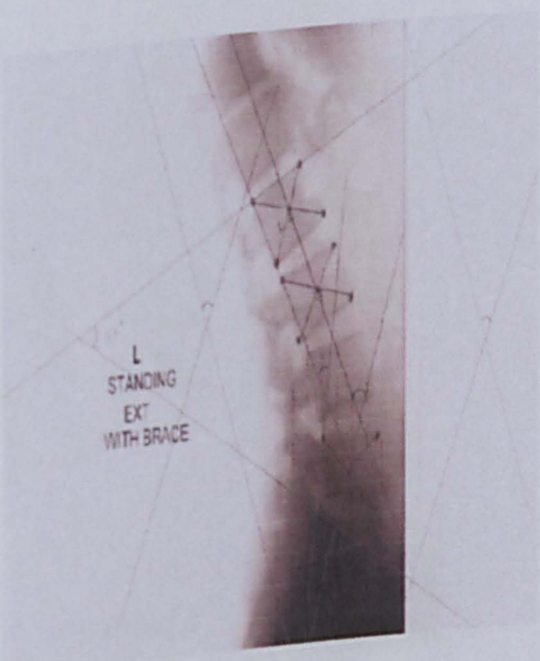
Example of measurement of lumbar lordosis using Cobb, centroid and posterior tangent for subject 8 during (a) neutral standing, (b) extension without LSO, and (c) extension with LSO





(a)

(b)



(c)

Figure 5.9

Example of measurement of lumbar lordosis using Cobb, centroid and posterior tangent for subject 9 during (a) neutral standing, (b) extension without LSO, and (c) extension with LSO

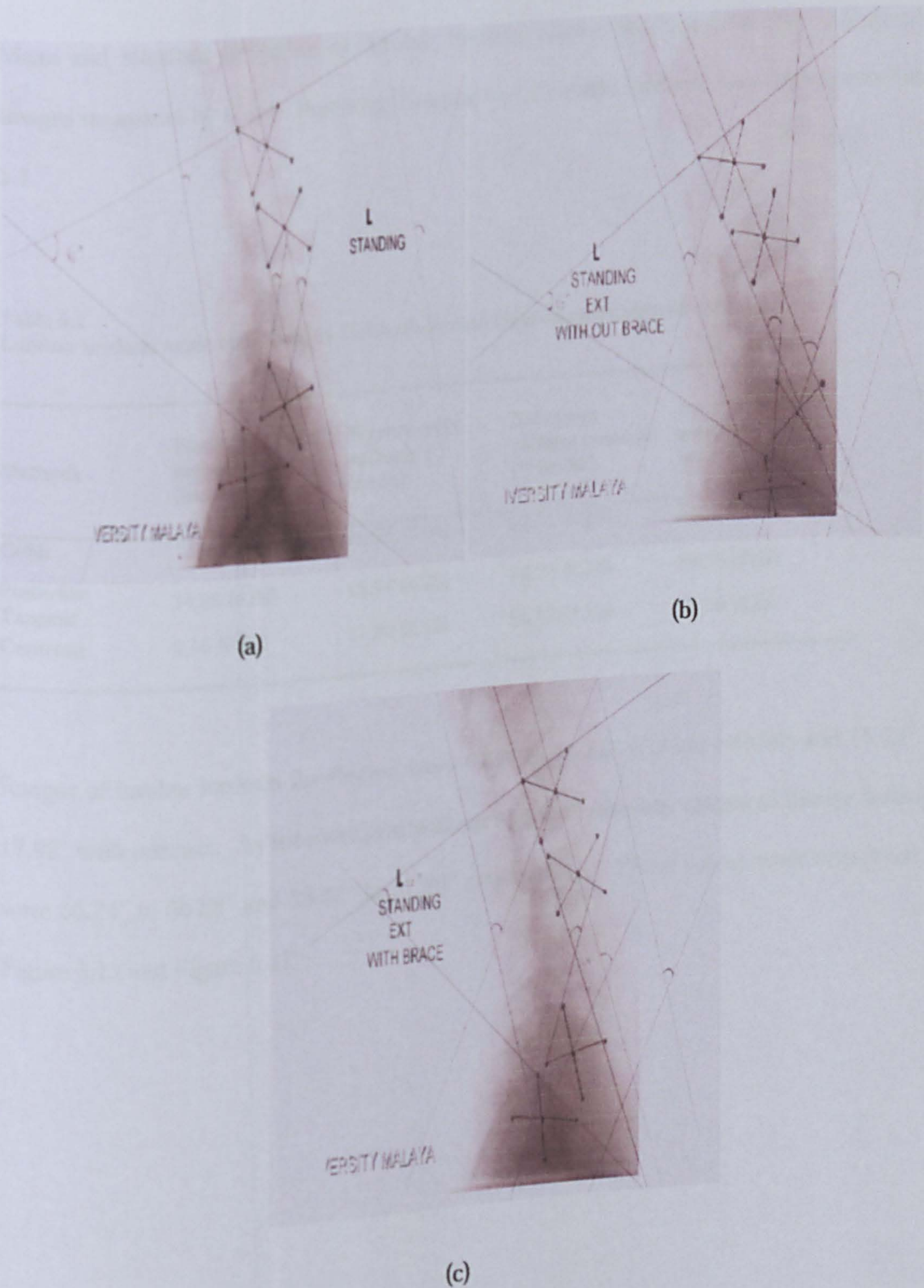


Figure 5.10

Example of measurement of lumbar lordosis using Cobb, centroid and posterior tangent for subject 10 during (a) neutral standing, (b) extension without LSO, and (c) extension with LSO

Mean and standard deviation of lumbar lordosis angles obtained from the radiographic images measured by Cobb, Posterior Tangent and Centroid methods was depicted in Table 5.1.

Table 5.1
Lumbar lordosis angle measured by Cobb, Posterior Tangent and Centroid methods.

Methods	Flexion without orthosis(°) (n=25)	Flexion with orthosis (°) (n=25)	Extension without orthosis (°) (n=25)	Extension with orthosis (°) (n=25)
Cobb	12.20 (1.88)	16.36 (2.58)	51.72 (2.15)	54.56 (3.46)
Posterior Tangent	14.88 (4.02)	15.24 (4.25)	36.24 (6.14)	39.92 (3.62)
Centroid	6.16 (0.89)	17.92 (2.10)	56.88 (2.73)	57.96 (2.65)

Ranges of lumbar lordosis for flexion were 6.16° to 14.88° without orthosis and 15.24° to 17.92° with orthosis. As for extension without and with orthosis, ranges of lumbar lordosis were 36.24° to 56.88° and 39.92° to 57.96° respectively. These values were visualized in Figure 5.11 and Figure 5.12.

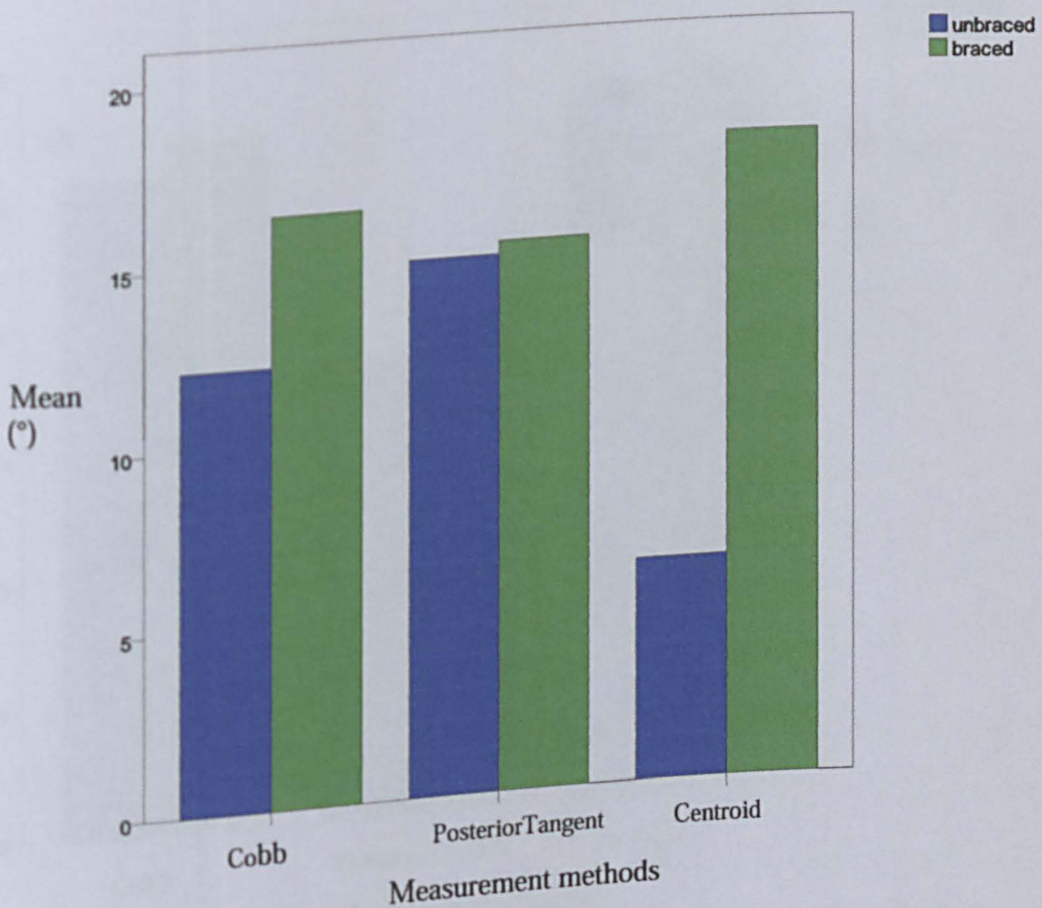


Figure 5.11

Trunk flexion with orthosis (braced) and without orthosis (unbraced) measured by Cobb, Posterior Tangent, and Centroid methods.

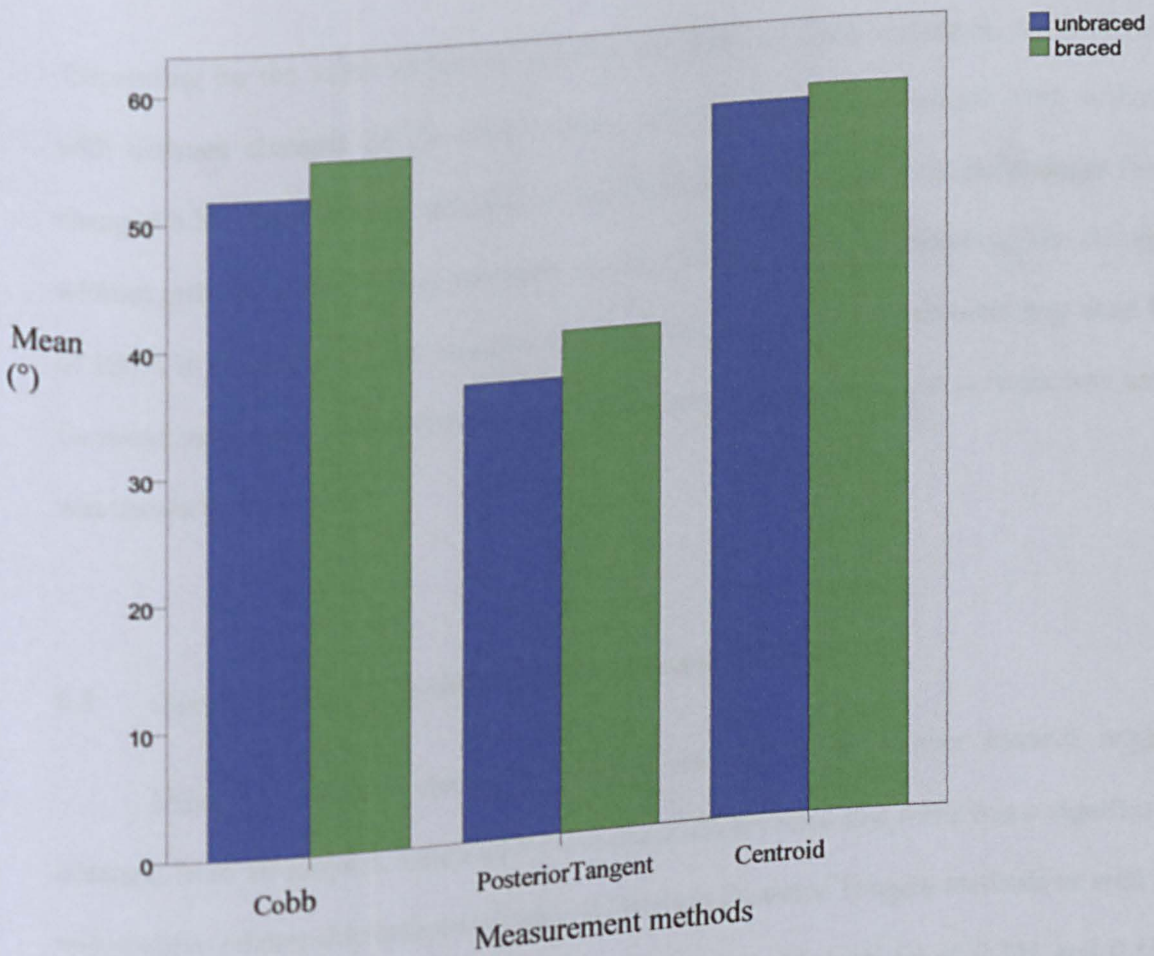


Figure 5.12

Trunk extension with orthosis (braced) and without orthosis (unbraced) measured by Cobb, Harrison Posterior Tangent, and Centroid methods

Both position showed an increased value of lumbar lordosis when the lumbosacral orthosis was attached. In getting the percentage of changes when lumbosacral orthosis was attached during particular posture, the following equation was applied:

$$\frac{angle\ (with\ orthosis) - angle\ (without\ orthosis)}{angle\ (without\ orthosis)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Depending on the value of lumbar lordosis measured by Cobb technique, trunk flexion with orthosis changed 34.1% from without orthosis and trunk extension with orthosis changed 5.5% from without orthosis. As for Posterior Tangent methods, the changes from without orthosis in flexion and extension were 2.4 % and 10.2 % respectively. The changes of 190% in flexion and 1.9% in extension were indicated when measurement was done by Centroid technique. Amplification in lumbar lordosis value when the orthosis was used was shown in the results.

5.3 Correlation between different measurement methods

Using the Pearson correlation method, analysis of 50 lumbar lordosis angles obtained from 10 subjects measured by five observers revealed that there was a significant and positive relationship between Cobb and Harrison Posterior Tangent methods as well as between Cobb and Centroid methods with correlation coefficients (r) of 0.344 and 0.488 respectively, which was significant at the 0.05 and 0.01 level (Table 5.2) in trunk flexion with and without orthosis. In trunk extension, there was significant correlation only between Cobb method and Centroid method with correlation coefficients (r) of 0.283 at the significant level of 0.05 (Table 5.2).

Table 5.2
Relationship between Cobb and other methods implemented to obtain lumbar lordosis of trunk flexion and extension with and without orthosis

Movement	Variables	Correlation Coefficient (r)	Significant Level
Flexion	Cobb vs Harrison Posterior Tangent	0.344*	0.015
	Cobb vs Centroid	0.488**	0.000
Extension	Cobb vs Harrison Posterior Tangent	0.150	0.426
	Cobb vs Centroid	*0.283**	*0.047*

Note: n=50
**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

5.4 Paired-sample t-test and ANOVA measurements

Paired-sample t-test was carried out for the three measurement methods (Cobb, Posterior Tangent, and Centroid) to compare means of trunk flexion (with and without orthosis) and extension (with and without orthosis) that were correlated. By analysing the data using SPSS, Tables 5.3, 5.4, and 5.5 were obtained.

Table 5.3
Paired-sample t-test for Cobb method

Pair	Position	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
		Lower	Upper			
Pair 1	Flexion without - flexion	-7.8186	-.5014	-2.347	24	.028
Pair 2	Extension without-extension	-5.1465	-.5335	-2.541	24	.018

Measurement of the x-ray images using Cobb technique indicated a difference in the degree of trunk flexion and extension when the lumbosacral orthosis was put on. In order to test this hypothesis, paired-sample t-test was done. Test of mean difference using this technique in flexion with and without orthosis yielded a relatively small t value of -2.347 significant at $p = 0.028$, and t value of -2.541 at significant level of $p = 0.018$ for extension (with and without orthosis). Therefore, it can be concluded that the changes in the degree of trunk flexion and extension were significant when the orthosis was attached.

Table 5.4
Paired-sample t-test for Centroid method

Pair	Position	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
		Lower	Upper			
Pair 1	Flexion without - flexion	-15.4564	-8.0636	-6.566	24	.000
Pair 2	Extension without-extension	-5.7818	3.6218	-.474	24	.640

As for Centroid technique, $p = 0.00$ showed that the changes in degree of trunk flexion was significant when the lumbosacral orthosis was attached. However, there were no significant changes of trunk extension as depicted in Table 5.4.

Table 5.5
Paired-sample t-test for Posterior Tangent method

Pair	Position	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
		Lower	Upper			
Pair 1	Flexion without - flexion	-4.4773	3.7573	-.180	24	.858
Pair 2	Extension without-extension	-7.7432	.3832	-1.869	24	.074

Test of mean difference in trunk flexion and extension measured by Posterior Tangent technique concluded that the use of orthosis did not significantly change the way the trunk moves whether in flexion or extension, with the p value of 0.858 and 0.074 respectively.

Further analyses of differences between trunk flexion and extension with and without orthosis were investigated using analysis of variance, ANOVA. In flexion (Table 5.6), the significant differences were only yielded by Cobb and Centroid methods with F-ratio of 5.78 and 43.69, which were significant at the 0.05 level respectively. These results indicated that, there were great changes of lumbar lordosis in trunk flexion when the orthosis is attached, measured by Cobb and Centroid methods. However, the change depicted by Posterior Tangent method was small and not significant. As for trunk extension (Table 5.7), all those three methods implemented showed insignificant differences when orthosis was attached onto the subjects during the movements. The analysis yielded significant results with F-ratio of 3.84 (p = 0.056), 0.343 (p = 0.56) and 1.21 (p = 0.277) at 0.05 level for Cobb, Centroid, and Posterior Tangent methods respectively.

Table 5.6
ANOVA comparison of methods implemented to evaluate the differences in flexion with and without orthosis

		Sum of Squares	df	Mean Square	F	Sig.
Cobb Angle	Between Groups	216.320	1	216.320	5.782	.020
	Within Groups	1795.760	48	37.412		
	Total	2012.080	49			
Centroid Angle	Between Groups	1728.720	1	1728.720	43.691	.000
	Within Groups	1899.200	48	39.567		
	Total	3627.920	49			
Posterior Tangent Angle	Between Groups	1.620	1	1.620	.035	.853
	Within Groups	2249.200	48	46.858		
	Total	2250.820	49			

Note: n= 50 (25 data for flexion with LSO and 25 data for flexion without LSO)

Table 5.7
ANOVA comparison of methods implemented to evaluate the differences in extension with and without orthosis

		Sum of Squares	df	Mean Square	F	Sig.
Cobb Angle	Between Groups	100.820	1	100.820	3.837	.056
	Within Groups	1261.200	48	26.275		
	Total	1362.020	49			
Centroid Angle	Between Groups	14.580	1	14.580	.343	.561
	Within Groups	2041.600	48	42.533		
	Total	2056.180	49			
Posterior Tangent Angle	Between Groups	169.280	1	169.280	1.212	.277
	Within Groups	6706.400	48	139.717		
	Total	6875.680	49			

Note: n=50

5.5 Correlation coefficient between observers

Analysis of intra-observers variability was carried out using Pearson's correlation coefficient in SPSS. The fundamental equation of this analysis was discussed in Section 4.5 of Theoretical Analysis chapter. Correlation coefficient was the strength of a linear relationship between sets of measurements (Vrtovec *et al*, 2009). In this study, Pearson's correlation coefficients between observers were implemented to Cobb method data during flexion and extension with and without LSO. Table 5.8 shows that the correlation coefficients (r) between observers were highly significant at the level of 0.01 with r ranging from 0.946 to 0.980. These data indicated that the variability between observers were small and could be neglected.

Table 5.8

Pearson's correlation coefficient between observers

		Observer 1	Observer 2	Observer 3	Observer 4	Observer 5
Observer 1	Pearson Correlation	1	.968**	.967**	.959**	.968**
	Sig. (2-tailed)		.000	.000	.000	.000
	N	20	20	20	20	20
Observer 2	Pearson Correlation	.968**	1	.946**	.951**	.978**
	Sig. (2-tailed)	.000		.000	.000	.000
	N	20	20	20	20	20
Observer 3	Pearson Correlation	.967**	.946**	1	.980**	.948**
	Sig. (2-tailed)	.000	.000		.000	.000
	N	20	20	20	20	20
Observer 4	Pearson Correlation	.959**	.951**	.980**	1	.958**
	Sig. (2-tailed)	.000	.000	.000		.000
	N	20	20	20	20	20
Observer 5	Pearson Correlation	.968**	.978**	.948**	.958**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	20	20	20	20	20

**. Correlation is significant at the 0.01 level (2-tailed).

n = 20 (5 data of trunk flexion without LSO, 5 data of trunk flexion with LSO, 5 data of trunk extension without LSO and 5 data of trunk extension with LSO)

5.6 Summary

Lumbar lordoses ranged from 6.16° to 14.88° without orthosis and 15.24° to 17.92° with orthosis for trunk flexion. For trunk extension with and without orthosis, lumbar lordoses ranged from 39.92° to 57.96° and 36.24° to 56.88°, respectively. Correlation among the methods was significant. In addition, there was a significant difference between lumbar lordosis of trunk flexion measured by Cobb and Centroid techniques. However, the changes in trunk extension with and without orthosis measured by Cobb, Centroid, and Posterior Tangent methods were insignificant. High inter observers reliability was depicted. Present results indicated that the lumbar lordosis increased when the lumbosacral orthosis was used in both flexion and extension movements.

CHAPTER 6: DISCUSSION

The present study is the first to investigate the effects of a commonly used lumbosacral orthosis in a local hospital, radiographically by mean of lumbar lordosis. The orthosis used was a semirigid orthosis prescribed for low back pain patients to restrict trunk flexion and extension. Normal, young, and healthy subjects were chosen to acquire significant effects in the evaluation of the use of orthosis. In addition, the BMI of all subjects were in the range of normal weight therefore eliminating the probability of associated low back pain.

Low back pain is an enormous clinical and public health problem that is associated with high health-care and social cost (Andersson, 1998). The muscles and ligaments around the lumbar spine may influence posture. Such postural changes can be a source of low back pain (Murata *et al*, 2002). The curvature of the spine is an important variable in characterizing postures and movements of the trunk and is of particular interest for the understanding of low back problems (Minitski *et al*, 1998). The relationship between lumbar lordosis and low back disorders has received considerable attention and several methods have been developed to measure the lumbar lordosis, including the Cobb, Centroid, and Posterior Tangent methods (Jae *et al*, 2010). Clinical observations have suggested that maintenance of the normal lumbar lordotic curve is associated with the prevention of spinal disorders (Tsuji *et al*, 2001).

The main finding of the present study is that, lumbar lordosis is different in flexion and extension movements when lumbosacral orthosis was attached onto the subjects and this scenario indicated that wearing the lumbosacral orthosis caused changes in lumbar motion. The higher the lumbar lordosis angle, the lower is the angle of trunk motion. As illustrated in Figure 5.11 and Figure 5.12, all those methods indicated increasing of lumbar lordosis when lumbosacral orthosis was used both in trunk flexion and extension. Present results indicate that the lumbar lordosis is higher when the lumbosacral orthosis is attached. The lumboscral orthosis used in this study was a non-extensible LSO because it was made of polyester and nylon materials. Non-extensible LSO provides superior performance in limiting trunk motion and increasing trunk stiffness (Cholewicki *et al*, 2010). The theoretical analysis stated that 75% of lumbar flexion and extension occur at the lumbosacral spine thus, LSO was used to restrict these movements and it was expected to show significant effect.

In this study, a significant correlation between the methods implemented was depicted in trunk flexion. This is due to the validity and accuracy on measuring the lumbar lordosis angle by radiographic analysis and also referred as Cobb's method (De Carvalho *et al*, 2010), thus it is crucial to compare Posterior Tangent and Centroid methods with this gold standard, Cobb method. Furthermore, it was concluded that a good to high reliability is associated with the segmental Cobb angle for interobserver and intraobserver measurements (Tayyab *et al*, 2007). However, in trunk extension, a significant correlation can only be seen between Cobb method and Centroid method. This may due to irregularities of L1 and S1 endplates that confused the observers with several options when drawing the lines, especially the superior endplate of S1 was often poorly visualized because of the overlying iliac bones or tilted vertebrae (Andreasen *et al*, 2007). Moreover, both Cobb and Centroid techniques would consider the segmental vertebrae of the lumbar spine and this was not required in the technique of Posterior Tangent method. Harrison *et al* (2001) stated that these methods have similar reliability of readings but different utilities.

Paired-sample *t*-test and ANOVA were carried out to compare means of degree of trunk flexion and extension with and without orthosis. Measurement of the x-ray images using Cobb technique concluded that the degree of trunk flexion and extension significantly changed when the orthosis was attached. As for the Centroid technique, the significant difference was only shown in trunk flexion and there was no significant change of degree in trunk extension. Both tests indicated that, in trunk flexion and extension measured by Posterior Tangent technique concluded that the used of orthosis did not significantly change the way the trunk moves. Although the findings were controversial, Cobb and centroid techniques confirmed that there were positive effects showed by the use of orthosis in trunk flexion and extension (Cobb technique only).

Studies of lumbar lordosis are important because they provide the information of the most mobile segments and frequent sites of trauma, disc problems, degeneration, stenosis, and instability (Lin *et al*, 2001). Among the three methods implemented, Cobb method was the most referred method in the literatures, not only because it was the first established method used in assessing radiographic images, but it also provides a simple and quick measurement of lumbar lordosis (Chen, 1999b). According to Harrison *et al*, 2001, the Centroid method resulted in smaller measurement of angles compared to Cobb and Posterior Tangent method was only true for the lumbar lordosis value of flexion without orthosis as referring to the present study. Instead, the lumbar lordosis angles measured by Centroid method were highest compared to the other methods both in flexion and extension with orthosis. However, it has been stated by researchers that differences of up to 10° in lumbar lordosis angle would be clinically acceptable (De Carvalho *et al*, 2010). Advantages and disadvantages of these methods were thoroughly discussed in the literatures (Harrison *et al*, 2000; Harrison *et al*, 2001). Measurement error could arise as a result of differences in subject positioning during imaging, image quality, subject performance and so on (Mannion *et al*, 2004).

In the present study, results obtained from the Cobb technique were compared to the results obtained from previous researchers (Table 6.1). This comparison was expected to be reliable because of the deployment of normal, unimpaired subjects.

Table 6.1
Comparison of measured (Cobb technique) and literature for lumbar lordosis value

Position	Measured, Mean (SD) n=50		Literature, Mean (SD)			Remark
	Lordosis(°)	Reduction of lordosis (°)	*Lordosis (°)*	Reduction of lordosis (°)	*Author s*	
Flexion	16.4 (2.9)	4.2 (1.0)*	23.5 (13.9)	4.2 (8.3)*	Huynh *et al*, 1998	3D model analysis
			16.0 (9.0)	6.0 (2.0)	Thoumie *et al* 1998	Implementation of electrogoniometer
Extension	54.6 (3.5)	2.9 (1.4)*	44.3 (14.1)	0.6 (6.5)	Huynh *et al*, 1998	3D model analysis
			30.0 (10.0)	6.0 (1.0)	Thoumie *et al* 1998	Implementation of electrogoniometer

* indicates amplification of lumbar lordosis

According to the summarized data in Table 6.1, the present study indicated amplifications of lordosis angle in both flexion and extension with orthosis. This finding is in agreement with the study carried out by Chen (1999b), the higher the lumbar lordosis angle, the lower is the angle of trunk motion. However, in the study carried out by Huynh *et al* (1998), amplification of lordosis angle was only seen in the flexion data. However, in extension, the lumbar lordosis angle reduced by 0.6°. As in the study investigated by Thoumie *et al* (1998), reductions of 6.0° of lordosis angles were observed in both flexion and extension with orthosis. Previous researchers stated that changes in posture of total lumbar spine depended on the individual and the characteristics of the lumbosacral orthosis used in the particular study, which increased or decreased lumbar lordosis. In addition, lordosis angles are varied in the postural changes caused in individuals by wearing the orthosis (Thoumie *et al*, 1998). As concluded in the theoretical analysis, the increase in abdominal pressure tends to extend and elongate the spine. By doing so, the lumbar lordosis was straightened and the force required in extensor musculature was reduced, thus relieving the compressive loads off the spine (Bartelink, 1957). Moreover, lumbar lordosis of low back pain patients was lower than normal person (Tsuji *et al*, 2001). Therefore, any attempt to maintain the lordotic angles should facilitate the increments of these values. Thus, as depicted in the present study, the use of lumbosacral orthosis has proven to be a method to increase the lumbar lordosis angles.

It was difficult to make accurate comparisons between studies because different evaluation techniques were implemented and different lumbosacral orthoses had been investigated. Moreover, biomechanical effects vary from one orthosis to another (Huynh *et al*, 1998). As the lumbar spine flexes, the lordosis flattens and then reverses at its upper level and as the flexion increases, the surface of the vertebral body would face more vertically thus increasing the shearing force due to gravity. In extension, anterior tilting increased the lumbar lordosis and was commonly a result of lengthening of the abdominal muscles and possibly tightness in the hip flexors (Norris, 1995).

The quantitative measurement techniques implemented in the present study were recognized as Degree 1 of automation where manual measurements were applied. Although there were many developed techniques that emerged as methods for quantitative measurements, those techniques were improvised from this technique. Results from this technique were commonly analyzed using data analysis software. Statistical parameters such as standard deviation and correlation coefficient could be obtained automatically through this software. These methods were easy and fast in obtaining the effects of LSO on trunk movements.

In a nutshell, radiography is the most commonly used method to assess sagittal spinal curves. Although it is invasive and costly, it provides practitioners with a simple and quick technique of observation. In the lumbar spine, fixation to at least four to five vertebral levels above and below the segment of instability are required to achieve stability (Benzel, 2001). Therefore, the use of lumbosacral orthosis is acceptable for those purposes. It is known that lumbar lordosis, or the degree of lumbar curvature, contributed significantly to maintaining spinal balance (Schuler *et al*, 2004) and has been considered as an important clinical factor among people with low back pain (Hicks *et al*, 2006). In a position in which the lordosis decreases, intradiscal pressure increased, and the increment of intradiscal pressure may become a factor of low back pain (Murata *et al*, 2002). Thus the use of lumbosacral orthosis can be claimed as a promising alternative tool to facilitate the treatment of low back pain because it is capable of increasing the lumbar lordosis angles.

CHAPTER 7: CONCLUSION

The present study evaluated the effects of lumbosacral orthosis used in a local hospital by implementation of radiographic technique. It was focused on the changes of lumbar lordosis angle when LSO was attached onto subjects in particular movements. The efficacy of lumbosacral orthosis used in therapeutic and prevention options in practice can be evaluated by determination of the lumbar lordosis. Data was obtained using standard measurement methods of lumbar lordosis. Investigators have previously developed different radiographic methods to evaluate lumbar lordosis such as Cobb, Centroid, and Posterior Tangent methods which are implemented in this study. These methods resulted in increasing in lumbar lordosis angles when the lumbosacral orthosis is attached onto the subjects during trunk flexion and extension. The increment of the lumbar lordosis angles is correlated with the study carried out by Cholewicki (2004) and Minitski *et al* (1998). Values of lordotic angles for flexion and extension obtained in this study were also compared to the results obtained by Huynh *et al* (1998) and Thoumie *et al* (1998) by implementation of Cobb technique. It is concluded that, when the LSO is attached, the loads increased thus increasing the lumbar lordosis. The higher the lumbar lordosis angle, the lower is the angle of trunk motion (Chen, 1999), proved that, by wearing the LSO, trunk gross motion would be restricted which is believed to reduce the low back pain (Huynh *et al*, 1998).

This study is an invasive technique to obtain internal lumbar spine geometry. For future comparison of the results, non invasive techniques such as skin markers (Lee *et al*,

1995) and external marker videography (Miyamoto *et al*, 1999) should be applied to the same subjects to investigate the reliability and accuracy of the finding. Nevertheless, further study should be focused on investigation of reliability of these methods as determined by observers. Inter-observers reliability were carried out and indicated that the correlations between observers were very high.

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